Shoulder Strength and Scapular Position in Swimmers

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Dissertation submitted in fulfilment of the requirements for the degree of

Doctor of Philosophy

College of Health and Medicine

University of Tasmania

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November 2018

Statements and Declarations

Declaration of Originality

This thesis entitled "Shoulder strength and scapular position in swimmers" contains no material which has been accepted for a degree or diploma by the University of Tasmania or any other institution, except by way of background information and duly acknowledged in the thesis, and to the best of my knowledge and belief no material has previously been published or written by another person except where due acknowledgement is made in the text of the thesis, nor does the thesis contain any material that infringes the Copyright Act 1968.

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- Professor Karen Ginn (University of Sydney): Advised on study design (particularly study 4), interpretation of results and manuscript drafts and revisions.
- Dr Cecilia M Kitic (Sports Performance Optimisation Research Team, College of Health and Medicine, University of Tasmania): Advised on statistical analysis, study design and manuscript draft for study 1.
- Dr Thomas Hartley (College of Health and Medicine, University of Tasmania): Advised on statistical analysis and manuscript revisions for study 4.

Additional support was provided by the following people:

- Justin Ockerby (College of Health and Medicine, University of Tasmania): Assisted with data collection for study 1, 2 and 3. Rachel Austin (College of Health and

Medicine, University of Tasmania): Assisted with data entry and follow-up for study 4. Assistance with the electronic based questionnaire was provided by Kevin Lyall.

Publications and Presentations

Journal Publications

- **McLaine SJ**, Ginn KA, Kitic CM, Fell JW and Bird M-L. The reliability of strength tests
- performed in elevated shoulder positions using a hand-held dynamometer. *Journal of Sport Rehabilitation.* (2016) http://dx.doi.org/10.1123/jsr.2015-0034
- **McLaine SJ**, Ginn KA, Fell JW and Bird M-L. Isometric strength profile of the young swimmer. *Journal of Science and Medicine in Sport.* 2017; 21(1):35-39
- **McLaine, SJ**, Ginn, KA., Fell, JW. and Bird, M-L. Scapular upward rotation in swimmers is symmetrical. *Physical Therapy in Sport.* 2017; 29(9-13)
- **McLaine SJ**, Bird M-L, Ginn KA, Hartley T and Fell JW. Shoulder extension strength: a potential risk factor for shoulder pain in young swimmers? *Journal of Science and Medicine in Sport.* Accepted November 13th, 2018

Conference Presentations

Oral Presentations

2015: **Australian Physiotherapy Association (APA) National Conference** (Melbourne, Australia). "*Factors contributing to the reliability of shoulder strength tests using a hand-held dynamometer for the overhead athlete*".

2015: **Shoulder and Elbow Physiotherapists of Australasia** (Sydney, Australia). "*Isometric strength profile of the young swimmer*".

2015: **Australian Physiotherapy Association (APA) Tasmanian State Conference** (Launceston, Australia). "*Shoulder strength in the young swimmer*".

2016: **International Conference of Shoulder and Elbow Therapists** (Jeju, South Korea). "*Isometric strength profile of the young swimmer*".

2017: **Sports Medicine Australia (SMA) Conference** (Langkawi, Malaysia). "*Scapular upward rotation in swimmers*".

Poster presentations

2015: **Annual Graduate Research Conference (SEIR) University of Tasmania** (Hobart, Australia). "*The reliability of shoulder strength tests for the overhead athlete".*

2017: **Sports Medicine Australia (SMA) Conference** (Langkawi, Malaysia). "*Shoulder extension strength in swimmers*".

Awards arising from this work

2017: **Best Poster: Sports Medicine Australia (SMA) Conference** (Langkawi, Malaysia). "*Shoulder extension strength in swimmers*".

Funding Support

Services for Australian Rural and remote Allied Health (SARRAH) Scholarship 2013-2016.

University of Tasmania International Travel Grant to attend the Sports Medicine Australia Conference, 2017.

Acknowledgments

The completion of this PhD thesis has been made possible only with the support of a wonderful team of people, to whom I am deeply grateful. Firstly, sincere thanks to my primary supervisor Dr Marie-Louise Bird. Your guidance, support, encouragement and patience has been invaluable and highly appreciated. You have supported me from places near and far but always with a presence that never felt faraway. This has been a positive learning experience because of your mentoring and generosity, going beyond your duty. I cherish the time we had in Canada and am inspired by your work ethic and achievements as a researcher and physiotherapist. Associate Professor James Fell, you have encouraged, motivated, inspired and pushed me to produce a body of work that I did not think I could achieve. Thank you for your positivity, humour, realism and constant belief in this work. Sincere thanks to Professor Karen Ginn, you have always encouraged me to strive for excellence in research and writing. Your communication skills and expertise in the shoulder area have helped guide me to the world of publications and academia. Thank you Dr Cecilia Kitic for your valuable support as an early supervisor and Dr Thomas Hartley for your knowledge, patience and support with statistical analysis. My sincere gratitude to Dr Helen Walker, swimming coaches and the participating swim clubs of Tasmania and Melbourne for assistance with data collection and sourcing pain-free swimmers (not an easy task). Importantly, thanks to the many swimmers who volunteered to take part in this research. I would like to acknowledge and thank Justin Ockerby for assistance with data collection, Rachel Austin for help with data entry and Simon Balster for improving my skills in shoulder assessment and measurement techniques.

I am grateful to the University of Tasmania for support in travel, providing equipment and a pleasant space to work. Even though this university is without a School of Physiotherapy, I felt welcome and part of a dynamic and productive Sports Performance Optimisation Research Team (SPORT). The Services for Australian Rural and remote Allied Health (SARRAH) provided financial support to allow me to start this educational journey, for which I am thankful. Thank you to my work colleagues and friends at Active Physio and Physiotas, for your understanding, support and flexibility. It has felt like a long and slow journey but made easier with great work mates, discussions and laughs. To Dr Emma Zadow, thank you for your encouragement and positive support but above all, for your friendship. You demonstrated achievements that inspired me to continue. Sincere thanks to all my fellow PhD candidates that I have worked with over this time. We have all shared support, coffee, wine, food and the highs and lows of such a journey. Thank you to the running girls, for keeping me sane through running and your enduring support.

To my parents Kay and Gavin Dawson and parents-in-law, Robert and Maureen McLaine, thank you for always supporting our family in many pursuits. You have set an inspiring work ethic and shown all of us the love and value of learning. To Jack and Adele, I dedicate this to you. I am ever so grateful for your constant love, understanding, encouragement and patience, allowing me to complete this project. I hope that in some way it provides inspiration to you both for your exciting journeys ahead. I am so lucky to have you both by my side and forever thankful. My final thank you is to my amazing husband, John. Without you, this PhD would not have been started or endured with any level of stability. Your voice of reason, ability to make me laugh (even if it is a dad joke) and reminders to rest are appreciated, even if I did not think so at the time! Thank you for your belief, help, tolerance and calmness when it was most needed. For 25 years, we have supported each other to pursue our goals and I am so grateful for your constant love and support. I look forward to more family time and adventures ahead.

This has been a valuable experience of learning not only of academia and all this thesis represents but also of life skills and persistence. Thank you to everyone who has shown me the way forward.

General Abstract

Background and Aims

Shoulder pain is common in swimmers, resulting in many young athletes leaving the sport. Despite the investigation of factors associated with shoulder pain in swimming, no consensus exists regarding risk factors for the development of swimmers' shoulder pain. Clinicians commonly assess shoulder strength and scapular position, which have been postulated as factors contributing to swimmers' shoulder pain. However, normative data is lacking, making it difficult to identify optimal parameters for shoulder strength or scapular position. Indeed, until normal parameters are defined using reliable and valid assessment tools and procedures, the relevance and association of these factors with shoulder pain in swimmers, remains uncertain.

The overarching aim of this research was to investigate the relationship (association and predictive value) of shoulder strength and scapular upward rotation (UR) with the development of shoulder pain in young swimmers. To complete this investigation, four concomitant studies were undertaken. The first study aimed to examine the reliability of measurements taken with two clinically useful tools, the hand-held dynamometer (HHD) and the inclinometer, in elevated shoulder positions (90° and 140° shoulder abduction), that are relevant to swimming. The second and third studies aimed to establish normative data for shoulder strength in pain-free swimmers (internal rotation [IR], external rotation [ER], flexion [FL] and extension [EX]) and scapular UR in the functional, elevated shoulder positions of 90° and 140° shoulder abduction. The fourth study aimed to investigate prospectively whether shoulder strength or scapular UR had any association with, or predictive value for, the development of shoulder pain in young swimmers.

Methods and Results

A protocol for the measurement of isometric shoulder IR, ER, FL and EX strength using a HHD in elevated shoulder positions was tested for reliability in supine, prone and sitting positions. Good to excellent intra-rater reliability was found for all shoulder strength tests (ICC

0.87-0.99) which was not affected by body position. The minimal detectable change (MDC) percentage was <16% for every test and ≤11% for all tests performed in supine (Chapter 3). The reliability for scapular UR measurements in 90° and 140° of shoulder abduction, using an inclinometer was also established (ICC 0.62-0.86). Standard error of measurement (SEM) values ranged from 1.2° to 2.7° (**Appendix D**).

Following the establishment of a reliable protocol, shoulder strength and scapular UR angle measurements were performed on 85 pain-free swimmers (mean age 15.5; range 14-20 years[yrs]) who swam a minimum of six hours per week. Training and shoulder pain history were recorded via a questionnaire and established that 32% of swimmers had a history of shoulder pain that caused the swimmer to miss or modify two or more swim training sessions. Strength measurements normalised to body weight (BW) and strength ratios for IR:ER and FL:EX were calculated to establish normative data for the group (Chapter 4). Relative strength differences between males and females were found ($p<0.002$); however, there were no differences in shoulder strength ratios. Relative shoulder strength was the same for the dominant and non-dominant arms (except for shoulder EX in males), and for the swimmers with and without a history of shoulder pain for all strength tests.

Scapular UR angle measurements were found to be highly variable between swimmers, with a large range of values recorded (Chapter 5). The mean (±SD; range) scapular UR angle recorded at 90° and 140° shoulder abduction was 30° (±8.7; 10-50°) and 52° (±7.8; 30-70°) respectively. However, side-to-side symmetry for scapular UR was found within swimmers and was not affected by a history of shoulder pain or arm dominance. This was confirmed when a sub-group of swimmers (n=17) who reported a history of unilateral shoulder pain were investigated using paired t-tests. No differences in scapular UR angles were found between shoulders with and without a history of pain ($p\geq0.11$).

To explore any relationship between shoulder strength and scapular UR angle and the development of shoulder pain, a longitudinal study was conducted (Chapter 6). Swimmers were followed up via a questionnaire emailed initially at a minimum of nine months and again up to 24 months (for non-responders and if pain was not reported on the initial questionnaire) after testing. The questionnaire aimed to establish if significant shoulder pain had been experienced by the swimmer in the 24 months after testing and if so, in which shoulder. Analysis of the strength data from 37 (47%) swimmers who responded (27 shoulders with reported pain and 47 without pain) was performed using Mann Whitney U tests and receiver operating curves (ROC). A relationship was confirmed between low shoulder EX strength in males (and consequently a higher FL:EX strength ratio) and the development of shoulder pain ($p=0.04$). Furthermore, the predictive value of shoulder EX strength was fair (0.72; $p=0.03$) for males, with a cut off value for EX strength calculated at below 13.5% BW. There were no differences between the swimmers who development shoulder pain and those who did not for shoulder rotation strength, scapular UR (**Appendix J**), swim training hours, age or shoulder pain history.

Conclusions

This body of work has established a reliable testing protocol and normative strength values for shoulder FL, EX, IR, ER, shoulder strength ratios and scapular UR values, which are specific to a young swimming population. The results provide a reference point for clinicians and indicate that the unaffected shoulder is valid for comparison in the assessment of shoulder strength and scapular UR, regardless of a history of shoulder pain. The results from the longitudinal study support functional shoulder strength testing of young swimmers, finding that reduced shoulder EX strength is a potential risk factor for the development of shoulder pain in young male swimmers. Low shoulder EX strength may help identify swimmers at risk of developing shoulder pain, specifically, males with shoulder EX strength below 13.5% BW.

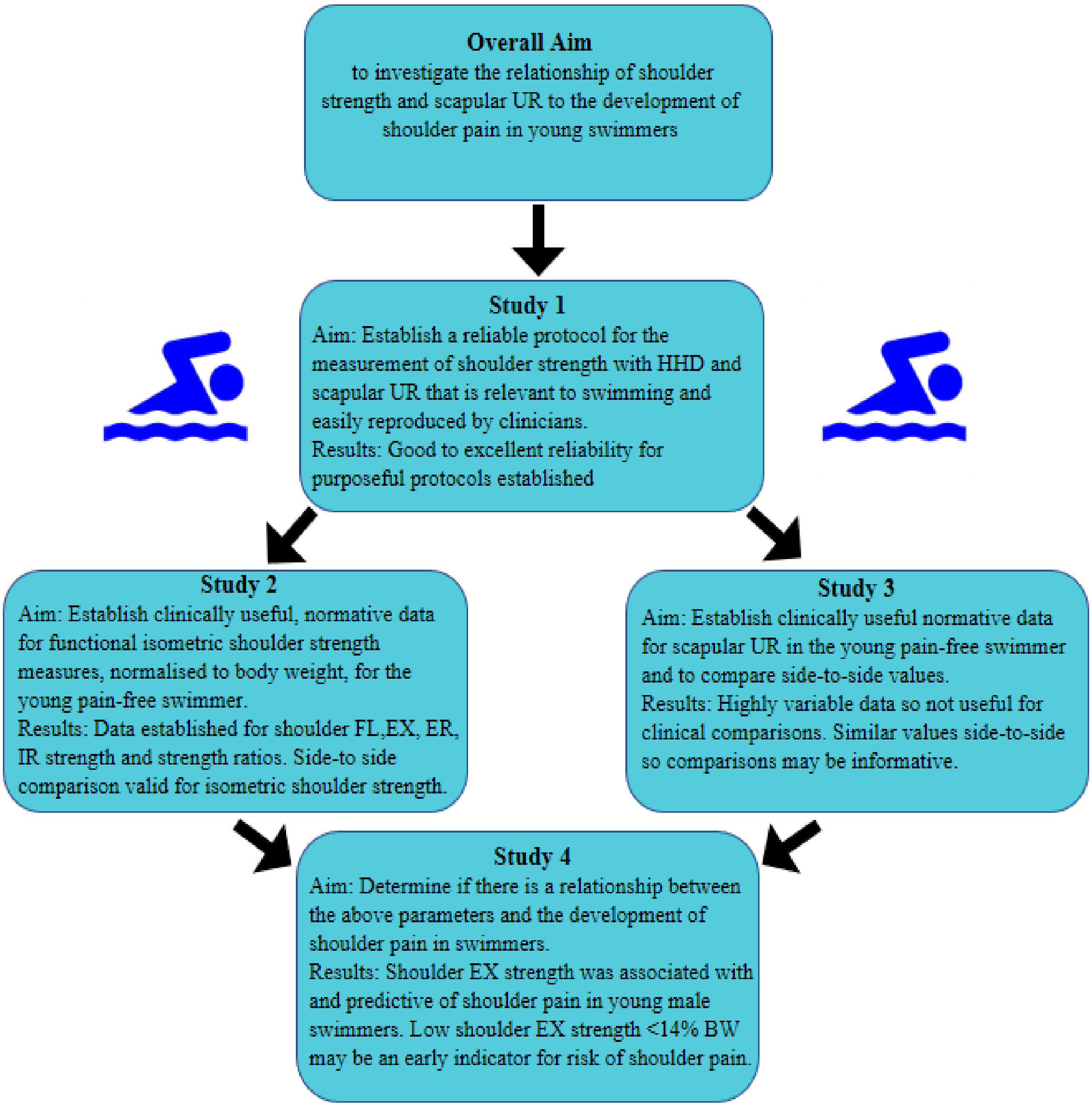

Figure 1 *Overview of research findings*

BW, body weight; ER, external rotation; EX, extension; FL, flexion; HHD, hand-held dynamometer; IR, internal rotation; UR, upward rotation

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Abbreviations

Abd	abduction
Add	adduction
AE	athletic exposure
AUC	area under the curve
BW	body weight
CI	confidence interval
Conc	concentric
DOM	dominant side
Ecc	eccentric
ER	external rotation
EX	extension
FL	flexion
HHD	hand-held dynamometer
ICC	intraclass correlation coefficient
IR	internal rotation
MDC	minimal detectable change
N	Newtons
n	number
NON	non-dominant side
ROC	receiver operating curve
ROM	range of movement
SD	standard deviation
SEM	standard error of measurement
UR	upward rotation
y/yrs	year/years

Infrequent abbreviations used through the thesis are defined *in situ*

Chapter 1. Introduction

1.1 Background

It has been clearly established that the development of shoulder pain in young swimmers is a significant problem. Consequently, sports medicine clinicians treat a high number of swimmers for shoulder pain. With prevalence rates up to 91%, shoulder pain causes many young swimmers to cease training and even leave the sport.[1]

The nature of shoulder pain is multifactorial and identification of specific shoulder pathology relevant to pain is difficult but may not be necessary when addressing swimmers' shoulder pain. Alternatively, identification and objective assessment of physical deficits around the shoulder may assist our understanding and treatment of swimmers' shoulder pain. Clinical assessment can drive treatment and positive outcomes without knowledge of pathology. [2] Many musculoskeletal factors have been associated with swimmers' shoulder pain, including shoulder muscle strength, range of movement, flexibility, shoulder laxity, scapular position and strength of other regions including the trunk. [3-5] Arguably, the most common modifiable physical factors to address include shoulder range of movement, muscle strength around the shoulder and scapular position, all of which must be considered when implementing treatment and prevention programs for swimmers.

On numerous occasions, I have assessed young swimmers with shoulder pain, suspecting that their shoulder might not yet meet the demands of this sport. Strengthening exercises have been provided, aiming to achieve adequate shoulder strength and scapular UR for the swimmer, without clear evidence for such interventions. Clinical questions with respect to swimmers' shoulder strength and scapular position have provided the motivation for this research in swimming. Direction for clinicians in the treatment and prevention of shoulder pain in swimmers is lacking, leaving numerous unanswered questions: How strong are young swimmer's shoulders? Where should the scapulae be positioned? Are there implications, such as shoulder pain, for any deficits in shoulder strength? Unable to source answers to these clinical questions, an investigation of shoulder strength and scapular position in young swimmers was instigated.

The overarching purpose of this research was to investigate any association of shoulder strength and scapular UR with the development of shoulder pain in young swimmers using clinically reproducible protocols. This thesis is comprised of a comprehensive narrative literature review and four related studies. Initially, reliability was established for testing protocols that can be effectively implemented by a sole clinician. Secondly, shoulder strength and scapular UR data were collected for pain-free swimmers to establish and explore a normative base. Finally, a longitudinal investigation was conducted to determine any relationship between shoulder strength and scapular UR and the development of shoulder pain in this young sporting group. The outcomes of this thesis add to our understanding and ability to answer the clinical questions around shoulder strength, scapular UR and shoulder pain in swimmers.

1.1.1 Clinical testing protocols relevant to the swimmer and their reliability

The reliable assessment of strength and scapular UR for swimmers is pertinent in elevated shoulder positions, as force during swimming training and competition is repeatedly generated in this position. Moreover, shoulder pain and impingement have commonly been reported in the recovery position and early pull-through phase of the freestyle swim stroke, when the shoulder is positioned in 90° abduction and full elevation respectively.[6, 7] The clinical assessment of shoulder strength and scapular UR performed in ranges replicating these elevated positions serves to identify deficits that may compromise shoulder function for the swimmer.

An objective and reliable shoulder strength assessment is essential in research and clinical situations for valid assessment and informed decision-making. Clinicians have commonly assessed shoulder strength using manual muscle tests, a technique that grades strength from one to five according to their ability to move a limb against gravity and increasing resistance.[8] Despite the simple grading system, manual muscle testing is not a reliable technique and lacks the rigor of a quantitative measure, particularly when a strength test is graded four or more.[8] The availability of affordable strength testing tools that are portable has increased and many clinicians now have access to a hand-held dynamometer (HHD), enabling quantification of objective strength assessments. As a result, the reliability of the HHD has been well documented for the measurement of isometric shoulder strength at ranges at and below shoulder height.[9, 10] However, shoulder strength tests have more relevance to the swimmer if performed above 90° shoulder elevation. Confirmation of the reliability of strength tests performed in elevated shoulder positions will enhance the body of literature on shoulder strength testing.

Scapular UR is the only scapular movement that can be assessed reliably in the clinic. The inclinometer, a cost-effective tool, is recommended for the measurement of scapular UR in static shoulder positions in the clinical situation.[11, 12] Scapular UR has consequently been investigated in general and swimming populations, both with and without shoulder pathology.[13-15] Reliability has been confirmed for scapular UR measurements ranging from a resting position up to 135° shoulder abduction when performed by a trained clinician using two inclinometers, one on the scapula and one measuring shoulder abduction.[14, 16] In the clinical situation, measurement of scapular UR may be restricted to a single inclinometer, with a goniometer used to confirm shoulder position. Hence, confirmation of the reliability of a single inclinometer and goniometer technique to measure scapular UR in elevated shoulder positions is required.

The reality of a busy clinical environment means clinicians perform physical assessments days or weeks apart without assistance from another person. The reliability of shoulder strength tests using the HHD has been confirmed in sitting, supine and prone test positions, when external stabilisation is applied to the upper limb but this is not always possible in a clinical environment.[17] Furthermore, previous reliability studies have reported *within session* shoulder strength and scapular UR test-retest measurements, again a less likely clinical scenario.[12, 17] The investigation of the reliability of scapular UR and shoulder strength tests performed without external stabilisation on different days is warranted and clinically valuable.

1.1.2 Shoulder strength in swimmers

Shoulder IR, adduction, and EX form the dominant movement pattern for swimmers' forward propulsion. Indeed, compared to the normal population, swimmers have increased IR and adduction strength and EX remains to be investigated.[18, 19] Increased swimming exposure results in the development of a shoulder strength bias in the directions in which force is generated through the water, evidenced by changes in strength measured over a season.[20] Previous investigations of swimmers' shoulder strength have largely focused on shoulder IR and ER strength. A rotation strength imbalance, quantified as a shoulder rotation strength ratio (IR:ER), has been reported between shoulder IR and ER strength in swimmers, with IR significantly stronger relative to ER.[19, 21] A similar strength bias for shoulder adduction compared to abduction has been shown but FL and EX strength measures have not been reported for swimmers.[19] Given the requirements for shoulder elevation in this sport, exploration of shoulder FL and EX strength and strength balance, in addition to IR and ER in elevated ranges will build a useful strength profile for swimmers.

1.1.3 Scapular upward rotation in swimmers

Adequate scapular UR is important for the swimmer in order to maintain acromiohumeral distance, optimal muscle length-tension relationships and congruency of the glenohumeral joint.[22] Therefore, the measurement of scapular UR may be included in a swimmer's shoulder assessment, with the expectation of increased UR angles with increasing shoulder abduction.[23] This movement is achieved via the coordinated action of the scapulothoracic muscles so deficits in scapular UR might inform inadequacies in muscle function and potentially direct exercise interventions.[24, 25] Changes in scapular UR have been reported for swimmers with shoulder pain, in a fatigued state and after a season of swim training.[13, 15, 26] Despite reports that inadequate scapular UR may be associated with shoulder pain in swimmers, results are conflicting with small sample sizes limiting conclusions.[13, 15] The investigation of scapular UR in pain-free swimmers is required to provide more clarity in this area.

1.1.4 Normative data

Normative data for physical measurements is required to identify deficits and understand potential relationships with musculoskeletal pain. This information has the potential to provide direction for intervention programs aimed at restoring the normal physical function to the swimmer. Normative data that is population specific (for age and sport) provides clinicians with an evidence-based reference point for objective measurements. However, there is a paucity of information with respect to normal parameters for isometric shoulder strength and scapular UR position for the swimming population. The clinical utility of the HHD and inclinometer could be increased if normal parameters for shoulder strength and scapular UR range of movement were known for swimmers. Furthermore, an understanding of the validity of a side-to-side comparison for shoulder strength and scapular UR in the swimmer may further inform a shoulder assessment.

1.1.5 Conclusions

Swimmers presenting with shoulder pain are commonly assessed with the aim of identification and correction of deficits in physical factors such as shoulder strength and scapular UR. The utility of shoulder strength and scapular UR assessments may be improved for clinicians through the generation of normative data specific to swimmers, using clinically reproducible protocols. Additionally, normative measures can provide a platform from which to investigate any relationship of these factors to the development of shoulder pain in young swimmers. Clinically useful and reliable protocols were firstly established in this research to collect normative data from pain-free swimmers for shoulder strength and scapular UR in elevated shoulder positions. From this database of swimmers' shoulder strength and scapular UR, the relationship of these two factors with the development of shoulder pain was explored.

1.2 Significance of the research

This thesis adds to our understanding of potential modifiable risk factors for shoulder pain in swimmers. Shoulder pain continues to be a significant problem for young swimmers, with factors contributing to risk requiring further research. Examination of shoulder strength and scapular UR is of significance as both physical factors are commonly assessed by clinicians and have been proposed as possible modifiable risk factors in the development of shoulder pain in swimmers. Before deficits for these factors can be identified and understood, normative parameters for pain-free swimmers are required but had not yet been established. Reliable outcomes for shoulder strength and scapular UR enable clinicians to compare a swimmer's shoulder assessment with a reference point for normality using protocols that are reproducible in the clinic. The four studies in this thesis collectively, have formed an investigation of the relationship between shoulder strength and scapular UR and the development of shoulder pain in swimmers. This may assist in the early identification of young swimmers at risk of developing shoulder pain.

1.3 Research Aims

The aims of the research presented in this thesis were to:

1. Establish the reliability of protocols that can be easily reproduced by clinicians for the measurement of isometric shoulder IR, ER, FL and EX strength and scapular UR.
2. Establish and explore clinically useful, normative data for functional isometric shoulder strength measures, normalised to body weight, for young pain-free swimmers.
3. Establish and explore clinically useful data for scapular UR in young pain-free swimmers.
4. Investigate any relationships between the above parameters and the development of shoulder pain in young swimmers.

1.4 Thesis Organisation

This doctoral thesis contains a series of four studies. The first three studies progressed from the establishment of reliable testing protocols to the investigation of isometric shoulder strength and scapular UR in young pain-free swimmers. This formed the platform for the fourth study, a longitudinal investigation, which investigated the relationship of these factors with the development of shoulder pain.

Chapter 1: This overview and general introduction, included the background, rationale, significance, aims and layout for this thesis.

Chapter 2: A review of the literature explored background information to support the investigations carried out for this thesis. Factors (modifiable and non-modifiable) associated with shoulder pain in swimmers were firstly explored. Secondly, prevalence and pathology relevant to shoulder pain in swimmers were discussed. A review of the functional anatomy of shoulder muscles is followed by a summary of the influence of pain on shoulder muscle function. Finally, the literature exploring the measurement of two modifiable factors, shoulder strength and scapular UR, was reviewed.

Chapter 3: The first study and publication, established the reliability of the HHD shoulder strength testing protocol, designed to be functional to swimmers and useful for the single clinician (research aim 1). The strength testing protocol was employed for study two.

SJ McLaine, KA Ginn, CM Kitic, JW Fell, ML Bird. The reliability of strength tests performed in elevated shoulder positions using a handheld dynamometer *Journal of Sport Rehabilitation.* 2016; 25(2)

Chapter 4: The second study and publication presented normative shoulder strength data for young pain-free swimmers using the protocol established in the first study (research aim 2). Between group differences were explored for sex, side of dominance and a history of shoulder pain.

SJ McLaine, KA Ginn, JW Fell, ML Bird. Isometric shoulder strength in young swimmers. *Journal of Science and Medicine in Sport.* 2018; 21 (1): 35-39

Chapter 5: Scapular UR values for pain-free swimmers were established and explored in the third study and publication (research aim 3). A range of values and side-to-side comparisons within swimmers were reported.

SJ McLaine, KA Ginn, JW Fell, ML Bird Scapular upward rotation position is symmetrical in swimmers without current shoulder pain *Physical Therapy in Sport* 2018; 29:9-13

Chapter 6: The final study and publication within this thesis presented the findings of a prospective investigation via a questionnaire distributed to swimmers following shoulder strength tests and scapular UR measurements. This prospective longitudinal study explored any potential relationship between shoulder strength and the development of shoulder pain (research aim 4).

SJ McLaine, ML Bird, K Ginn, T Hartley, JW Fell. Shoulder extension strength: a potential risk factor for shoulder pain in young swimmers? Manuscript accepted: November 13th, 2018; *Journal of Science and Medicine in Sport*

Chapter 7: A discussion of the research findings presented in this thesis included clinical implications and preliminary recommendations for clinicians, coaches and researchers working with young swimmers. Potential for future research, limitations and concluding comments were included in this chapter.

Chapter 2. Review of Literature

2.1 Introduction

Shoulder pain is a substantial problem for swimmers, which can result in time away from swim training and competition, possibly terminating ongoing participation in the sport. In fact, the shoulder is the most frequently injured region reported in swimming.[27] Shoulder pain has been reported in 51-91% of young swimmers under the age of 17 yrs, the number dependent on the pain definition employed in the study.[1, 28-30] Despite the establishment of a high incidence of shoulder pain in young swimmers, uncertainty remains with respect to the identification of risk factors for the development of shoulder pain.

An expansive body of literature proposes various factors as contributing to the risk of a young swimmer developing shoulder pain; however, the evidence is varied and it is difficult to formulate conclusions around risk. Some musculoskeletal factors, such as shoulder strength and range of movement are modifiable, yet without a basis of what is normal, which can be defined as “an appropriate state of physical function”, deviations are unclear.[31] Characteristics such as sex, age and previous history cannot be changed but if these contribute to risk then knowledge of co-existing factors that can be changed is highly valuable. Therefore, with the aim of injury prevention through effective intervention, attention must be given to factors that are modifiable. Further investigation of modifiable factors that may be associated with shoulder pain in young swimmers, is required. For the purposes of this review and research, young swimmers include swimmers from 14 to 20 yrs. This group are of interest as many young swimmers leave the sport due to shoulder pain so the direction of further investigation through a review of potential risk factors and identification of gaps in the literature is vital.

This chapter commences with a review of the literature related to factors associated with shoulder pain in young swimmers and its prevalence in this population. A discussion of the functional anatomy of shoulder muscles is followed by an analysis of the literature associated with two modifiable factors; shoulder strength and scapular UR and their modes of assessment.

2.2 Factors Associated with Swimmers' Shoulder Pain

Many modifiable and non-modifiable factors, potentially associated with shoulder pain in swimming, have been examined in the literature (**Figure 2.1**). These may be categorised into four main groups: demographics (sex, age, height, injury history), activity (training load, time away from swimming, other exercises, use of equipment such as hand paddles), biomechanics (stroke technique, breathing pattern) and musculoskeletal factors (shoulder strength and endurance, range of movement, shoulder laxity, strength of other regions, scapular position).[4, 13, 28, 32, 33] The identification of modifiable factors associated with and predictive of shoulder pain in swimmers may provide rationale to address problems. Interventions, including exercise prescription and changes to coaching practice can be further informed by addressing significant gaps in the literature related to shoulder pain in young swimmers.

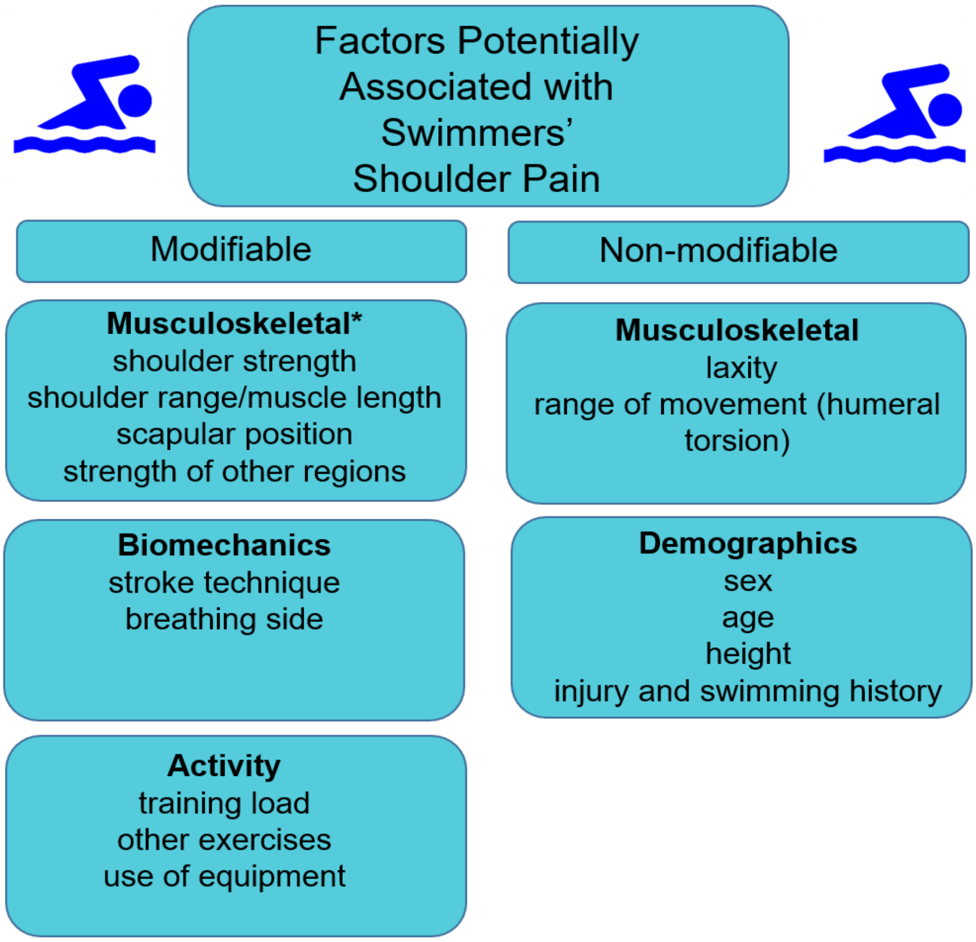

Figure 2.1 *Modifiable and non-modifiable factors potentially associated with shoulder pain in swimmers.* *common clinical assessments

2.2.1 Modifiable Factors

Shoulder strength

Shoulder strength is a physical factor that is both measurable and responsive to change via an exercise intervention.[34, 35] Shoulder strength and strength ratios, which indicate the balance between muscle groups, are modifiable factors that have been related to shoulder pain and are commonly assessed in the swimmer. The association of these strength measures with shoulder pain has been widely explored for well over two decades; yet questions around the association of strength and shoulder pain remain.[6, 11, 13, 21, 36-38] A shoulder strength profile for an athlete is reflective of their individual sport and the dominant movement pattern which can result in muscle strength biases, is often described as a strength imbalance.[18, 39] Therefore, trained swimmers would be expected to be stronger in the directions of their dominant movement pattern of shoulder IR, adduction and EX, when compared to the general population, with strength changes observable over a single swim season.[18, 20]

Shoulder rotation strength

A significant portion of the literature investigating shoulder strength in swimming populations has focussed on shoulder IR and ER strength. This is primarily because IR is a dominant and powerful movement in the swim stroke, with subscapularis (an internal rotator), active throughout the entire freestyle stroke.[40] Competitive swimmers were found to have increased shoulder IR strength compared to a matched control group of non-swimmers (n=47; age 18-23 yrs), yet no difference was found for ER strength. The same strength bias for IR was found in another study, with a cohort of similar age and sample size, that compared swimmers with a matched control group a few years later.[18] Increased shoulder IR strength results reported for swimmers over a season further support this strength bias.[20, 21] However, it is not clear if this IR strength bias is a positive adaptation or a potential problem for swimmers.

The strength of shoulder ER and IR has also been used to inform shoulder strength balance and stability around the glenohumeral joint. Associations between shoulder pain and a change in shoulder rotation muscle balance for sporting populations which include throwing, handball and tennis have been reported previously.[41-44] Hence, it is not surprising that shoulder rotation strength and subsequent strength ratios in swimmers are arguably the most extensively investigated of all the factors potentially associated with swimmers' shoulder pain.[3, 5, 21, 36] Reduced shoulder IR strength and subsequently reduced IR:ER ratio have been associated with shoulder pain in young swimmers (n=43; age 12-14yrs) when tested using a HHD.[5] Similarly, swimmers with shoulder pain recorded lower IR strength compared to a pain-free control group, which although not itself significant, contributed to a significant IR:ER strength ratio difference (p=0.02).[36] In contrast, no differences in IR strength has been reported between young swimmers with and without shoulder pain when tested using either isokinetic dynamometry (IKD) [18] or a HHD.[3] Some of the differences in outcomes may be due to strength testing performed on painful shoulders, as pain tolerance will vary between individuals and force output will be compromised in the presence of pain.[45, 46] The influence of pain on muscle strength tests is discussed further in this review in section 2.4 under the title "muscle function and pain". Despite numerous investigations of swimming cohorts, no consensus exists regarding the relationship of shoulder rotation strength and pain in the swimming athlete,[4, 32, 33] highlighting the need for further exploration.

Shoulder strength: other than rotation

Strength of the shoulder in other movement directions has been investigated in swimmers, as has a measure of shoulder muscle endurance. No correlation has been found with shoulder pain and shoulder adduction, abduction and elevation strength or with scapular strength tests for different groups of competitive swimmers.[3, 5, 36] Maintenance of shoulder strength over numerous repetitions (50), reported as endurance ratios, were investigated via IKD.[37] Reduced shoulder ER and abduction endurance correlated with shoulder pain in this young group of swimmers (r=0.55-0.69), although findings are limited to the small cohort (n=32) and have not since been reproduced. It seems that increased shoulder endurance and strength are associated with swimming training but the relationship with the onset of shoulder pain is to be confirmed.[21] Further investigation of other shoulder strength tests that are functional to swimming in directions such as shoulder EX and adduction may help inform any association of shoulder strength shoulder pain.

Challenges to the investigation of strength in swimmers

Inconclusive findings around shoulder strength and pain in swimmers are likely influenced by study design. There is a lack of longitudinal, prospective studies with adequate power to confirm or quantify any potential relationship, be it cause or effect.[4, 32, 47] Additionally, methodological factors, including small sample sizes, pain definitions, different test protocols and tools and, testing in the presence of pain, contribute to varied findings, limiting inferences around association and prediction. Of five studies that investigated shoulder strength, the range of study sample size varied from 15 to 169 (median=27); and the investigations included strength tests performed in the presence of pain (see **Table 2.1** for further data). For more detail on shoulder strength testing methodology, refer to section 2.5.1 of this review

Considering the challenges to study design and conflicting results, it is difficult to make any conclusions regarding shoulder strength and its relationship with shoulder pain in young swimmers. The implementation of injury prevention and treatment programs could be misdirected when uncertainty remains around shoulder strength as a risk factor for shoulder pain, highlighting the pertinent research question: what is normal strength for a young swimmer in the absence of pain and is it relevant to the development of shoulder pain?

Range of shoulder movement

While some limitations to shoulder range of movement are non-modifiable (humeral torsion; discussed later in this review), limitations due to soft tissue restriction might be modified through exercise interventions.[48] Adequate range of shoulder rotation and elevation is necessary for swimmers to optimise technique whilst avoiding impingement and potentially pain.[49] In particular, IR range is required to maintain a high elbow throughout the freestyle stroke so limited IR might be considered a potential problem for swimmers; however, the research suggests otherwise. Three studies with a young swimming cohort (15-25 yrs) have reported no association of IR and ER range of movement with shoulder pain in swimmers.[3, 36, 37] A more recent and larger investigation of elite swimmers also found no association with shoulder IR or ER range of movement and shoulder pain.[50] In contrast, a large 12 month prospective study reported that swimmers with high or low range shoulder ER (≥100° and <93°) were more at risk of developing shoulder pain compared to the swimmers with mid-range shoulder ER.[51] Reduced shoulder FL was associated with shoulder pain in one group of very young swimmers but this was not replicated in other age groups in a large cohort.[5] It appears that shoulder ER range of motion outside a range of 93-100° could be associated with shoulder pain in swimmers, but results do not support limited shoulder IR range of motion as a risk factor for this population.

Scapular position

Scapular position and movement is quantified using various methodologies and has been measured in swimmers to investigate any relationship with shoulder pain. Scapular dyskinesia assessment has been validated, using a simple yes/no outcome following observation of scapular movement; while scapular UR can be measured via clinically useful tools (inclinometer), or in the laboratory situation using tools that are more sophisticated.[11, 52] Scapular UR occurs with shoulder elevation to allow the glenoid fossa to maintain approximation with the humeral head and to enable optimal rotator cuff muscle length-tension relationships. Evidence suggests inadequate scapular UR is associated with shoulder pain in overhead athletes.[53] In a small group of swimmers with shoulder pain, scapular UR was less (2.5-4°) compared to those without pain after a swim training session, when measured at 45°, 90° and 145° of shoulder abduction ($p=0.008$).[13] Before the training session, there was no difference in UR between the groups, suggesting that pain was either a cause or effect of decreased scapular UR, perhaps due to muscle inhibition or fatigue.[54] Inadequate scapular UR has been associated with pain in other populations but further investigation is required to determine normal scapular UR position and whether this is a risk factor for shoulder pain in swimmers.

Strength of other regions

Core strength, often difficult to quantify, has been considered as a potential influence on swimmers' shoulder pain but has not been examined in the literature to the same extent as other factors, such as shoulder strength. Core strength has been assessed via endurance tests for prone and side bridge with majority of results suggesting no association between hold time and shoulder pain.[3, 5] In contrast, a young group, (12-14 yrs) within a larger cohort, without shoulder pain recorded a lower side bridge hold time compared to those with pain.[5] There is potential for bias during bridge holds, as these tests were comparing swimmers with and without current shoulder pain, thus the presence of pain may have inhibited performance in tests involving weight bearing through the upper limbs. Although commonly prescribed in the interests of injury prevention, the strength of other regions and their association with shoulder pain in swimmers is not clear.

Stroke technique

Swim stroke technique may change in the presence of shoulder pain and is a factor that coaches may address to reduce the risk of shoulder pain. However, a direct relationship between the development of shoulder pain and swim technique is difficult to assess, reflected by the paucity of investigations in this area. Positions of potential shoulder impingement have been described in the hand entry and recovery phase of the freestyle stroke, when the shoulder is in full FL and IR respectively.[49] Shoulder pain may develop in these positions, particularly when potential for impingement is increased through overreaching, crossing the midline at hand-entry, increased or decreased trunk rotation, increased IR or shoulder muscle fatigue.[55] Stroke length was reduced bilaterally and ER range was reduced in the dominant arm in a fatigued state but the consequence of this as a possible reason for shoulder pain was not investigated further in this study.[56] Furthermore, stroke specialty (freestyle, breaststroke and butterfly) has not shown an association with shoulder pain in young swimmers.[1, 5, 51]

Breathing pattern

Swimmers use a bilateral or unilateral breathing pattern (breathing to alternate sides or the same side), which may influence stroke biomechanics and subject shoulders to asymmetrical stresses. A bilateral breathing pattern was associated with shoulder pain in one group of very young swimmers (8-11yrs); however, for the other age groups in this large female cohort, breathing pattern was not associated with shoulder pain.[57] In this young, developing group of swimmers, the motor control and co-ordination of the upper limbs and body might be more challenged when breathing bilaterally. In support, breathing asymmetry and reduced arm coordination on the breathing side, was more evident in the non-expert swimmer when compared to the more experienced swimmer.[57] There is little evidence to support breathing side as a risk factor for shoulder pain in swimmers.

Training load

Swimmers start competing and training intensively from as young as eight years, commonly training more than six times per week.[1, 5] Consequently, young swimmers are often subject early to high training volumes, exposing the shoulder to repetitive loading. A swimmer in the high school age group at the elite level will typically have recorded between half and one million arm cycles per year, sometimes up to 16,000- 44,000 shoulder revolutions or 40-48 kilometres per week and it appears that reported training distances have not changed significantly over time.[1, 5, 28, 33, 40, 51]

Despite training load commonly examined as a risk factor for shoulder pain, any potential relationship has not been convincingly demonstrated. Various investigations including young swimmers (age range 8-20 yrs) have failed to identify an association between weekly swim distance and shoulder pain, even with swimmers training up to 44 kilometres on average per week.[5, 51, 58] However, in one of these studies, the most symptomatic age group (15-19 years) had the highest training load (16 hours per week).[5] A large training load for young, elite swimmers (mean age of 16 yrs) has been associated with supraspinatus tendinopathy, defined by a grading scale of magnetic resonance imaging (MRI) results.[1] Swimmers were two or four times, more likely to have tendinopathy if they trained for more than 15 hours or greater than 35 kilometres per week, respectively (r=0.48 and 0.37) compared to those who swam less. However, changes on MRI do not always correlate with shoulder pain,[59] which was the case in this group. The supraspinatus tendon changes correlated with pain on impingement testing; however, they did not correlate with swimmers' reported pain on activity or rest.[1]

Other exercises

Some studies have recommended dry land exercise programs for young swimmers, which may include warm up, stretching, strengthening, and core exercises with the aim of injury prevention.[29, 60, 61] However, measurable gains in strength, performance, flexibility and their relevance in injury prevention as a result of dry land training are yet to be confirmed. No association was found between dryland shoulder strength training (over 12 weeks) and shoulder pain in a small group of swimmers under the age of 18 years, despite gains in shoulder ER strength.[62] Gains in ER strength were also achieved in swimmers who participated in a strengthening program over 16 weeks but any relationship to shoulder pain was not explored.[61]

The frequency, duration and quality of a dryland exercise program has been explored further in a large study across eight swim clubs (n=197) to determine any effects on shoulder pain, positive or negative.[30] A regular warm-up frequency of more than five times a week was associated with reduced shoulder pain (p=0.04) but if programs were more than 10 minutes duration, there was a positive association with shoulder pain (p=0.04).[30]

Young swimmers train frequently, sometimes more than 30 hours per week, leaving little time for other activities, yet there is evidence that highlights the benefits of participation in other sports and the reduction of shoulder pain risk in swimming. Participation in other sports or activities, which included soccer, running and walking (water polo excluded), has been proposed as offering a protective mechanism via cross training.[5] A young female cohort with shoulder pain participated in another sport (mainly soccer) less frequently ($p \leq 0.04$) than those with no reported shoulder pain.[5] In this growing sporting population, it appears that a short warm-up (<10 minutes) and participation in other sports may be associated with an absence of shoulder pain but the influence of dry land strength training on the prevention of shoulder pain is not clear.

Use of equipment

Hand paddles and kickboards are commonly used during swimming training and have been postulated as potential contributors to shoulder pain in swimmers, possibly increasing shoulder load in impingement positions. The use of hand paddles and kickboards within a large survey group of competitive swimmers (n=1262) was reported to aggravate shoulder pain, although these swimmers were already symptomatic.[28] More recently, the use of equipment (hand paddles and kickboards) was not associated with shoulder pain in a large group of female competitive swimmers.[5] It is feasible that more recent changes in paddle size and style, in addition to careful use of equipment as a result of the first study, has contributed to this more recent finding of no association.[63, 64] A recent systematic review[4] concluded that there is no evidence that the use of training equipment is associated with the development of shoulder pain but advised to avoid using equipment in the presence of shoulder pain.

2.2.2 Non-modifiable Factors

Laxity

Shoulder joint laxity and instability are different entities with the second considered pathological, yet both have been considered as possible risk factors for shoulder pain in swimmers. It appears that the studies that have found a positive association of shoulder laxity with shoulder pain have defined laxity as a feeling of looseness, self-reported by the swimmers.[5, 28] A systematic review concluded that the level of certainty that joint laxity is associated with shoulder was moderate; however, this review included Masters swimmers in addition to young swimmers and laxity was again self-reported.[4] Laxity can exist without symptoms, particularly if shoulder muscle control is effective so the subjective reporting method may confound results. When measured objectively via glenohumeral joint translation measurement,[65] a prospective study over 12 months failed to show an association of clinical laxity with shoulder pain.[51] Overall, there is a scarcity of high-quality evidence that shoulder pain and laxity are associated factors in young swimming athletes.

Range of movement

Humeral torsion describes the orientation of the humeral head in relation to the shaft and can influence the range of shoulder rotation. It is associated with osseous changes and can vary between sides, particularly for the throwing athlete.[66] Hence, once present, a change in humeral torsion is a non-modifiable physical factor. The only study that has investigated humeral torsion in swimmers, measured humeral torsion and range of shoulder rotation movement and concluded that there was no association of either with shoulder pain.[50] Interestingly, the values for humeral torsion in swimmers were similar to the non-swimming population.

Sex

The level of certainty that one sex is more at risk of developing shoulder pain in swimming than another is low, as investigations of the association between shoulder pain and sex are contradictory.[4, 58, 67] No significant relationship was found between sex and shoulder pain or injury over a season in a small swimming cohort (n=34),[58] or in two larger groups; one investigated over 5 yrs (n= 94)[60] and the other during the 2009 FINA World Championships (n=1502).[27] Of five studies included in a systematic review investigating risk factors for shoulder pain in swimmers, only one found an association between shoulder pain and sex.[4] In this study, swimming was one of only two sports from eight that showed a greater number of shoulder injuries in the females (21.05 per 100 female participants compared to 6.55 for males).[67] This gender difference is in contrast to previous studies and was postulated by the authors to be a result of more rigorous training programs set by the women's coach. However, the differences are likely to be influenced by the pain definition used, which was based on seeking medical attention. Outcomes may have been affected by a reluctance to seek medical attention, time or access restraints (see **Table 2.2**).

Although not included in the systematic review mentioned above, two large retrospective survey-based studies (n=170 and 179) are worthy of mention.[30, 68] More female swimmers reported an episode of shoulder pain (56% compared to 45% of males; p=0.048) in a survey, which investigated the prevalence of shoulder pain 12 months prior.[30] The shoulder pain definition appears to be based on a numerical rating scale. Potential recall and selection bias may have influenced these results, as the eight swimming groups involved had different rates of reporting compliance, (higher for female swimmers) and training programs for the different clubs were diverse. In contrast, the other survey-based study,[68] using a model of regression analysis, found no significant differences in injury rates between the male and female swimmers. However, more specifically, the model identified that males were more at risk of developing shoulder pain if: swim training was commenced at a younger age; there was a history of swimming injury; or time was taken off from swimming.[68] To conclude, there does not appear to be a relationship between sex and shoulder pain in swimmers.

Age

Despite reports of increased shoulder pain prevalence in swimmers of high school age (15-18 yrs), there is no evidence that age is associated with shoulder pain in swimmers.[4, 5, 68] Age was not associated with shoulder pain in two large cross-sectional studies.[5, 30] Similar numbers of reported shoulder pain episodes were recorded for various youth age groups within a female cohort. [5] Assessed via a combination of outcome measures, 21.4% of swimmers aged 8-11 yrs, 18.6% aged 12-14 yrs and 22.6% of high school swimmers (15-18 yrs) reported shoulder pain and disability.[5] The consensus that age is not associated with shoulder pain in swimmers appears to be well supported in the literature.

Height

Young swimmers grow and develop through adolescence at various rates and times with accompanying height and muscular changes.[69] During periods of growth a rapid change in height, and thus lever length, without an associated increase in muscle may predispose young swimmers' shoulders to increased stress. In young female swimmers (8-14 yr age group), an increase in height was associated with increased shoulder pain, disability and dissatisfaction.[5] A review (**Table 2.1**) of potential risk factors calculated a mean effect size of 0.61 for height as a shoulder pain risk factor only for the age group from 8-14 yrs.[33] Interestingly, arm span was an indicator of performance time for young swimmers of a similar age (11-16 yrs).[69] This may suggest a possible scenario for the younger swimmer and the development of shoulder pain. The longer levers of the upper limbs in young, taller swimmers enhance swim performance; however, shoulder biomechanics may be suboptimal due to the ongoing stroke, motor control and strength development still required in young swimmers. Contradictory to this proposal, no relationship was reported for shoulder pain and height in a large retrospective study (n=197) for competitive swimmers[30] or for a prospective study (n=74) over 12 months.[51] The evidence to date does not clearly support a relationship between shoulder pain and increased height but further investigation during growth periods could be worthwhile.

Injury and swimming history

A previous episode of pain or injury may be associated with the onset of shoulder pain due to insufficient recovery time, inadequate rehabilitation or failure to address causative factors. Swimmers with a history of shoulder pain were more likely to sustain interfering or significant shoulder pain (4.1 and 11.3 times more likely, respectively).[51] Furthermore, a history of traumatic injury (either dislocation, fall or fracture) to the shoulder, was associated with shoulder pain in young female swimmers.[5] In one of the few studies employing risk analysis and an exposure based injury rate, swimmers were examined prospectively over a season and a history of injury to the same region (shoulder included) increased the injury risk rate two and a half times (IRR=2.46, 95% CI=1.75, 3.46).[58] In further support of this relationship, two reviews concluded that a history of shoulder pain is a potential risk factor for the development of shoulder pain with a moderate level of certainty and small to very large effect sizes, as summarised in **Table 2.1** (mean 0.61).[4, 33]

It is not surprising that reports of shoulder pain increase with time in the sport, with many young swimmers believing that shoulder pain is normal, continuing to train despite pain.[28, 70] Therefore, a swimmer is more likely to develop a history of shoulder pain through the natural course of exposure over time. A large survey of 1262 swimmers reported that 10% of young swimmers aged 13-14 yrs, 13% aged 15-16 yrs and 26% of older elite swimmers (15-18 yrs) reported current shoulder pain.[28] When questioned about any history of shoulder pain, numbers increased in all age groups, up to 73% for the young elite swimmers.[28] The literature suggests there is a relationship between a history of previous shoulder pain or injury and shoulder pain developing in swimmers.

Challenges

Throughout the literature, comparison of factors (for example; strength) associated with shoulder pain across different studies is difficult as the definition of what constitutes shoulder pain in swimmers is not consistent. The definition employed will impact on the number of reported incidents; therefore, clarity around definitions is important when reviewing injury or pain data.[71] In **Table 2.2** definitions used throughout the literature reviewed have been classified as: any physical impairment or pain, pain resulting in the swimmer seeking medical attention, or time-loss, (defined as pain resulting in a swimmer to miss or modify training or competition).[71] In some studies a pain episode is clearly defined and has been based on time-loss[51] others have used simple rating scores, based and rated on any pain complaint (1-3 mild-severe)[1, 18] and outcome measures related to pain, dissatisfaction and disability.[5] Other studies[30, 58, 60, 67] that have employed a definition based on seeking medical attention, could result in underreporting of pain due to poor access to resources, time restraints or reluctance to seek medical attention. The exploration of association and causal relationships will be enhanced when pain episodes are clearly and consistently defined.

The lack of clarity in the literature relevant to factors associated with shoulder pain in swimmers is exacerbated by inappropriate study design. To date, a common theme in study design throughout the literature is one of association rather than prediction, with analysis largely limiting conclusions around risk. Incorrect interpretation of associative and predictive relationships has been identified in the literature, with assumptions of predictive power made following analysis of association.[72] Therefore, this review of the literature has included factors potentially associated with shoulder pain in swimming and comment on risk is duly limited.

2.2.3 Summary of Factors

Factors related to shoulder problems in swimmers were reviewed in a meta-analysis which calculated effect sizes from a range of studies.[33] Factors investigated included swimmer characteristics, injury history, range of shoulder movement and strength, and are summarised in **Table 2.1**[33] This is a comprehensive review; however, limitations to the summary include the comparison of a large range of studies (varies from one to six) which use different pain definitions and populations. Normal distribution for the analysis of studies was not confirmed. Furthermore, the mean effect sizes reported are of limited value when ranges are large and extend in both directions, interpreted as a positive or negative association with shoulder pain. The summary of some of the factors considered in this review provided in **Table 2.1** has highlighted the large range of effect sizes, from which calculations and comparison of mean effect sizes are problematic. Only four factors (injury history, time off competitive swimming, increased height for one age group and functional strength ratio) demonstrated ranges in the same direction and a medium or greater (>0.5) mean effect size (**Table 2.1**).

A summary of the factors which may be associated with shoulder pain in swimmers, as detailed in this review of the literature is provided in **Table 2.2.** The review within this thesis concurs with two others suggesting that the overall evidence for potential risk factors and shoulder pain is low.[4, 33] A moderate level of certainty for risk of the development of shoulder pain in swimmers was reported by Hill et al.[4] for some modifiable factors (range of shoulder rotation, time off swimming, shoulder strength ratio and competition level).[4] No factors were reported to have a high level of certainty for risk or association with shoulder pain. Some factors, for example, clinical laxity and history of pain are non-modifiable once present and a high level of uncertainty remains, with insufficient evidence to make conclusions.

In conclusion, this review of the literature exploring factors associated with shoulder pain in young swimmers has highlighted that populations, definitions and outcomes are varied so conclusions regarding association and certainly risk, should be interpreted with caution. There is a need for future researchers to investigate potential modifiable risk factors, addressing the flaws in methodology discussed previously. The establishment of evidence-based prevention strategies for young swimmers is reliant on furthering our understanding of modifiable risk factors for the development of shoulder pain.

Table 2.1 *Factors associated with shoulder problems, adapted from Bradley et al., 2016[33]*

Factors investigated	Factors with potential positive association with shoulder pain in swimmers	Number of studies	Effect sizes: Cohen's *d* mean (range of means)
General swimmer characteristics	• ↑ time off competitive swimming	1	*0.97 (0.78-1.16)
	• ↑ weekly training load	4	0.34 (-0.31-0.85)
	• ↑ number yrs swimming	6	0.12 (-0.65-0.75)
	• ↑ height (8-14 yrs)	1	*0.60 (0.52-0.68)
	• Overall for height	2	0.22 (-0.38-0.68)
	• Overall for weight	2	0.08 (-0.41-0.61)
Injury history	• History of shoulder injury	3	*0.61 (0.28-1.34)
Shoulder laxity and range of movement	• Shoulder laxity present	2	0.40 (0.1-0.98)
	• ↑ ER range	6	0.38 (-0.19-1.97)
	• ↑ IR range	5	-0.20 (-1.03-0.46)
	• ↓ shoulder flexion range	2	0.01 (-0.9-0.61)
	• ↓ shoulder abduction range	1	-0.17 (-0.56-0.24)
Shoulder strength	• ↓ ER strength: (Conc & Ecc)	1	0.19 (-0.11-0.45)
	• ↓ ER strength HHD	2	0.09 (0-0.51)
	• ↓ IR strength: (Conc & Ecc)	1	-0.92 (-1.5- -0.49)
	• ↓ IR strength HHD	2	-0.13 (-1.02-0.26)
	• ↓ Conventional (Conc) ER:IR ratio,	2	0.43 (-0.24-1.66)
	• ↑ Functional (Ecc:Conc) ratio	1	*1.47 (1.24-1.7)
	• ↓ Endurance ratio (ER:IR)	1	-1.25 (-1.62-0.14)
	• ↓ Endurance ratio (Abd:Add)	1	-0.71 (-1.62-0.14)
General strength	• ↓ Core endurance tests	2	-0.17 (-0.57-0.37)

*medium or greater effect size with range limits both in the same (positive) direction.

Abbreviations: Abd, abduction; Add, adduction; Conc, concentric; Ecc, eccentric; ER, external rotation; HHD, hand-held dynamometer; IR, internal rotation; yrs, years; ↓ decreased; ↑ increased.

Table 2.2 *Summary of studies investigating factors associated with shoulder pain in swimmers*

Author, year Study design	Population (n) and age range or mean	Pain reported: prevalence proportion (or incidence or rate per AE)	Pain epsiode definition	Factors investigated	Associated with shoulder pain?
Beach, 1992**[37]** Comparative	n=32 (15-21 yrs)	69% 31% affecting swim ability	AP	• Shoulder ROM • Shoulder strength • Endurance ratio	• No • No • ↓ER and ABD
McMaster, 1993**[28]** Cross-sectional	n=1262 (total) Grouped: • n=993 (13-16yrs) • n=198 (15-16yrs) • n=71 (National team, mean age 19.5yrs)	 • 10% • 13% • 26%	AP	• Time in sport • Other equipment • Other exercise • Laxity (self-reported) • History of pain	• No analysis for association • Aggravated existing pain • Aggravated existing pain • No analysis for association • No analysis for association
Rupp, 1995**[18]** Comparative	n=22 (14-26 yrs)	23%	TL	• Shoulder ROM • Shoulder strength	• No • No
Bak, 1997**[36]** Comparative	n=15; (15-25 yrs) 8 no pain; 7 unilateral shoulder pain	NA	AP	• Shoulder ROM • Shoulder strength • Shoulder FL and Abd strength	• No • ↓ functional ER:IR ratio (ecc ER, conc IR) • No
Sallis, 2001[67] Retrospective over 15 yrs	n=3767 all sports (18-22yrs)	All injuries 49.7% (incidence)	MA	• Sex	• ↑ female swimmers sustained shoulder injuries (21.05 and 6.55 injuries per 100 participants)
Sein, 2008[1] Cross-sectional	n=80 (13-25 yrs)	91%	AP	• Training load • Laxity	• ↑ hours and mileage trained correlated with supraspinatus tendinopathy on MRI but not with pain on activity. • No association with pain during activity but correlated with pain on impingement test ($p<0.05$)

Wolf, 2009[60] Retrospective 5yrs	n=94 (college age: freshman to senior)	All injuries: 4 per 1000 AE 37% missed time (incidence)	MA	• Sex • Age	• No • ↑ for freshman level (early college yrs)
Mountjoy, 2010**[27]** Prospective in competition	n=1502 (14-37yrs)	5.9 per 1000 AE (incidence)	MA	• Sex	• ↑ female for shoulder injuries and other
Abgarov, 2012[68] Retrospective one season	n=170 (21 yrs)	All injuries 72% with 41% of these shoulder (incidence)	AP	• Sex • Training load/time in sport • Injury history	• Males: ↓ starting age, ↑ time off sport • No • Males
Tate, 2012**[5]**	n=169 (excluded Masters) Grouped: • n=42 (8-11 yrs) • n=43 (12-14 yrs) • n=84 (15-19 yrs)	 • 21.4% • 18.6% • 22.6%	AP	• Shoulder ROM • Shoulder strength • Scapular dyskinesis • Core endurance • Breathing pattern • Training load/time in sport • Other exercise: participation in another sport • Other Equipment (paddle use) • Laxity (self-reported) • Age • Height • Weight • History of injury	• ↓ FL range • ↓ IR • No • ↓ core endurance • No • ↑ hours • ↑ years swum • ↓ participation in another sport • No • No • No • No • No • Yes

Walker, 2012[51] Prospective one y	n=74 (11-27yrs)	38% SIP 23% SSI (incidence)	TL	• Shoulder ROM • Training load • Joint laxity • Height • Injury history	• High and low ER range ↑ risk of SIP & SSI • No • No • No • Yes, 4.1 & 5.2 x more likely to have SIP & SSI
Chase, 2013[58] Prospective one y	34 (18-23 yrs)	5.5 per 1000AE 39% shoulder (incidence)	MA	• Training load • Sex • Injury history	• No • No • Yes (other body areas included)
Harrington, 2014**[3]** Comparative	N=37 (mean 19.5 yrs)	35% 26 shoulders from 74	AP	• Shoulder ROM • Shoulder strength • Pectoralis minor length • Core endurance	• No • No • ↓ length at rest and stretch ($p<0.03$) • No
Tessaro, 2017**[30]** Retrospective one y	197 (11-20 yrs)	51%	AP	• Training load (volume) • Other exercise (dryland training) • Sex • Age • Height & Weight	• No ($p>0.1$) • > 10 mins warm up ($p=0.04$) • < 45 mins per dryland session • Females ($p=0.05$) • No ($p>0.3$) • No ($p>0.3$)
Holt, 2017[50] Cross-sectional	70 (20.1 yrs)	24%	AP	• Shoulder rotation ROM and humeral torsion	• No ($p=0.46$)

Abbreviations: AE, athletic exposures; AP, any pain; ER, external rotation; HHD, hand-held dynamometer; IR, internal rotation; MA, medical attention; mins, minutes; MRI, magnetic resonance imaging; N, number; NS, not stated; ROM, range of movement; SIP, significant interfering shoulder pain; SSI, significant shoulder injury; TL, time-loss; y, year; yrs, years; ↓ decreased; ↑ increased

2.3 Reporting Rates

The reported prevalence proportion of shoulder pain in young swimmers is varied (10-91%), depending on the population and time span investigated, and the definition used for shoulder pain.[1, 5] When reviewing risk and occurrence of pain episodes, it is important to differentiate between reports of incidence, the number of new cases during a specific time of exposure, and prevalence, the proportion of swimmers with pain at any given time. As summarised in **Table 2.2**, many swimming studies have reported prevalence proportions, an appropriate measure for this population, given that recurrences are common and many swimmers continue to swim with pain.[71]

The various definitions used for shoulder pain episodes add further challenges to injury rate comparisons between studies. [42] The choice of definition will influence the rate of reporting, with a definition based on any physical impairment likely to capture a higher number of injuries than one based on medical attention or time loss **(Table 2.2)**.[71] Based on a definition of any shoulder pain, 91% of young elite swimmers (mean age 15.9 ±2.7 yrs) in a cross-sectional study reported having shoulder pain, based on a modified, validated shoulder questionnaire.[1] Severity and frequency of pain (with activity, night and at rest) was scored using a rating scale 0-4, with 0 indicating no pain and 4 very severe. This rigorous questionnaire is likely to capture pain episodes that may not be recorded via a definition related to time loss, such as that employed by Walker et al.[51] Another, much larger questionnaire-based study, including young swimmers (n=274), reported a more modest figure for shoulder pain of 51%.[30] This prevalence study was retrospective over the previous 12 months, however, the definition for shoulder pain is not clear so it is difficult to compare this figure with the previously mentioned cross-sectional study.[1] It appears that any shoulder pain was recorded, as 31% of swimmers in the group who reported shoulder pain also reported a change in training due to pain (time loss).[30] These diverse results highlight the need for consistency in pain episode definitions and clarity around injury surveillance methodology.

Using a clear definition for interfering shoulder pain (time-loss definition), Walker et al.[51] investigated incidence rates for a young swimming population in a prospective study over 12 months. The incidence rate for significant interfering shoulder pain, defined as pain that interfered with training or competition, was reported as 38%. A significant shoulder injury was defined as an episode lasting at least two weeks and the incidence rate was lower at 23% but the differentiation between the two pain groups was clear.[51] In another cross-sectional study, a positive shoulder pain episode (18.6-23.6%) was defined via a complex rating scale (which combined the Penn shoulder score, a rating of dissatisfaction and a disability rating for swimming based on the DASH sport module) with different cut off values set for age groups.[5] The different methodologies and populations in the studies reviewed have highlighted the difficulties in comparing outcomes. In conclusion, despite varied definitions for shoulder pain episodes providing a range of outcomes, the evidence has convincingly demonstrated that shoulder pain is a common problem with significant impact on young swimmers. For future research it is recommended that the definition used for shoulder pain incidence is founded upon a clearly defined measure of time-loss as this is objective and easy to measure, despite the risk of under reporting.

2.4 Functional Anatomy

Shoulder muscle function

The functional demands of swimming are met via the optimal activation, pattern of recruitment and coordination of muscle groups around the shoulder. The axiohumeral, axioscapular and rotator cuff muscle groups all play an important role in positioning of the arm and scapula, to allow for pain free function in overhead activities.[73] Most importantly, the rotator cuff muscles (supraspinatus, infraspinatus, teres minor and subscapularis) provide a compressive force to centralise the humeral head in the glenoid fossa throughout range, providing stability to the glenohumeral joint. During swimming, strong forces provided by the muscles producing shoulder movements such as the latissimus dorsi, pectoralis major and teres major potentially destabilise the glenohumeral joint. However, coordinated contraction of the rotator cuff muscles resist these forces and maintain centralisation of the humeral head providing stability to the glenohumeral joint.

Rotator cuff muscles

Resisted shoulder IR and ER strength tests are commonly performed on swimmers as deficits may be relevant in swimmers with shoulder pain. During resisted shoulder IR and ER tests, the role of the rotator cuff muscles has been described as one of torque production specific to direction in a dependent, abducted, supported or unsupported arm.[57, 74, 75] During isometric shoulder ER in unsupported shoulder abduction, significantly high activity levels were reported for infraspinatus and supraspinatus, while subscapularis activity remained low. During IR, activity levels were significantly higher in subscapularis compared to infraspinatus and supraspinatus.[74] It has been postulated that when testing in this unsupported abducted shoulder position, the deltoid muscle provided dynamic stability and the rotator cuff muscles were not acting as a stabilising force couple but provided directional torque. Activity levels in the deltoid muscle remained moderate but unchanged during resisted IR and ER of the shoulder.[74, 76] During freestyle swimming similar directional patterns of rotator cuff muscle activity have been demonstrated. Infraspinatus and teres minor recorded the highest levels of activity during the external rotation dominant recovery phase, while subscapularis was more active during the IR dominant phase of pull through.[40]

Resisted shoulder FL and EX tests have also demonstrated rotator cuff muscle activity and are functional strength tests for swimmers. These strength tests have not been as extensively investigated in swimmers compared to shoulder rotation tests but are worthy in the assessment of shoulder strength, challenging the rotator cuff muscle group in a role of stabilisation, rather than torque production.[77] Although not performed on swimmers, muscle recruitment patterns measured during active shoulder FL through range in prone, confirmed that posterior rotator cuff muscles (infraspinatus and supraspinatus) were more active than the anterior rotator cuff muscle (subscapularis).[78] The most likely reason for the posterior rotator cuff activation is to provide dynamic shoulder stability by counterbalancing flexor muscle forces anteriorly translating the humeral head, thus confirming the stabilising role of the rotator cuff through shoulder sagittal motion. Similarly, activity levels of subscapularis were higher than the posterior rotator cuff muscles during loaded shoulder EX (in prone from 90° FL to arm by side) balancing the potential posterior translation forces of the shoulder extensors (latissimus dorsi).[77, 78] The multi-direction stabilising capacity of different parts of the rotator cuff has an important role in preventing unwanted humeral head translation throughout the dominant EX phase of the swim stroke. Hence, testing swimmers' shoulder EX strength is an important part of a shoulder assessment.

Motor recruitment in the absence of pain

Multiple studies demonstrate that shoulder muscle motor recruitment strategies remain the same regardless of load in pain-free populations; however, the levels of activation increase as load increases.[74, 75, 78] Similar muscle recruitment patterns have been demonstrated at low, medium and high loads for shoulder FL[77, 78], EX[77], IR and ER[74], suggesting that muscle recruitment strategies remain the same during a maximum strength test as when resisting a low load in the absence of pain. Such strategies also confirm the recruitment of many muscle groups rather than an isolated muscle during any resisted test, an important concept to consider in shoulder strength testing.

Axioscapular muscles

The axioscapular muscles are important in coordinating scapular movement with arm movement to maintain the congruence of the glenoid fossa to the humeral head. During arm elevation, such as is required in swimming, serratus anterior, levator scapulae, upper and lower trapezius muscles and the rhomboid muscles coordinate to move the scapula in directions of UR, lateral rotation and posterior tilt.[22, 79] Additionally, through activation of the axioscapular muscles, any potential destabilising forces on the scapula, resulting from contraction of other muscles including the rotator cuff group are resisted.[76, 79, 80] The stabiliser role of the axioscapular muscles has been confirmed by their increased levels of activity as arm support was decreased in the abducted position during a resisted muscle test[76] which systematically increases as activity in scapulohumeral muscles increases.[81]

High activity levels of the axioscapular muscles have been recorded during resisted shoulder IR and ER tests. Serratus anterior and middle trapezius demonstrated activity levels as high as or higher than pectoralis major and infraspinatus during isokinetically resisted IR and ER at 90° shoulder abduction.[80] Similarly, high levels of axioscapular activity were measured, during isometrically resisted IR and ER with greater trapezius and serratus anterior activity during ER.[74] Similar to the rotator cuff and axiohumeral muscle groups, the axioscapular muscles have demonstrated a similar muscle recruitment pattern to that adopted with low loads and increased activity with an increasing load.[78]

Very few studies have used EMG to explore axioscapular or rotator cuff muscle activity during swimming, most likely a reflection of the challenges presented by the aquatic environment.[82] A series of swimming specific investigations led by Pink,[40, 83, 84] which investigated muscle activity in all swim strokes, are the only EMG swim studies that have examined serratus anterior, rhomboids and upper trapezius, in addition to the rotator cuff group. During freestyle, upper trapezius and rhomboids demonstrated peak activity during hand entry and exit phases, to elevate, retract and stabilise the scapula, while infraspinatus was only active during the recovery phase, when the arm externally rotates to reach into elevation. Serratus anterior and subscapularis were reported as constantly firing throughout the stroke at levels, which ranged from 20-40% of a maximal manual test and therefore suggested to be prone to fatigue during swimming.[40] This confirms the importance of the activity of rotator cuff and axioscapular muscles during swimming. Consequently, functional strength tests that activate these muscles are recommended in the assessment of swimmers. While the literature often describes strength tests for scapular muscles and the rotator cuff muscle group separately, the axioscapular and rotator cuff muscles function together and cannot be isolated.

Muscle function and pain

In the presence of pain, shoulder muscle activation may be delayed, inhibited or redistributed resulting in changes in force production or movement.[46, 85] This has implications for the swimmer with shoulder pain, affecting the coordinated control of shoulder muscle groups throughout a large range.[24] This is evidenced by increased variability in the timing of scapular muscle activation in swimmers with shoulder pain compared to those without shoulder pain.[24] Accordingly, it should be considered that shoulder strength tests performed in the presence of shoulder pain may produce flawed outcomes. Thus, it is not clear if reduced shoulder strength, when measured in the presence of pain, is a result or consequence of pain.[5, 36, 37]. The research within this thesis addresses some of these gaps in the literature.

Changes in muscle activity in the painful shoulders of swimmers have been demonstrated in fine-wire EMG studies performed in the water during freestyle and butterfly swimming strokes.[40, 84] When compared to pain free shoulders, painful shoulders demonstrated decreased muscle activation for serratus anterior, subscapularis, upper trapezius, anterior and middle deltoid and rhomboids (at hand entry). Increased muscle activity was recorded for infraspinatus and rhomboid muscles (during pulling phase).[86] Large standard deviations in these EMG investigation suggest a high variability between swimmers indicating caution is needed in the interpretation of results. Additionally, the EMG studies were performed in the presence of shoulder pain, potentially confounding any association of altered muscle activity and highlighting the need for further studies exploring muscle function in the absence of shoulder pain.

In summary, patterns of muscle activity will occur during a swimming stroke which involve the recruitment and coordination of many muscles to both generate force and resist destabilising forces and this is impacted by the presence of pain. Consequently, shoulder strength tests performed in the absence of pain will provide a true indication of functional strength for the shoulder position and direction of movement tested.

2.5 Shoulder Strength

The assessment of shoulder strength is an important part of a thorough clinical assessment for the swimmer with shoulder pain, providing a foundation for clinical reasoning, rehabilitation and research. Functional stability and movement of the glenohumeral joint is reliant on optimal shoulder muscle strength. Therefore, strength tests need to be valid, reliable and functional, to provide useful information, ideally with normative values for comparison. To date IKD and HHD have been the principal tools used in the assessment of swimmers' shoulder strength.

Isokinetic dynamometry, considered the gold standard, lacks clinical utility due to the time-consuming set up, size and cost of the equipment.[10] However, IKD can be performed at varied speeds with different modes of muscle contraction (isometric, concentric and eccentric). The HHD, while limited to isometric tests (and more recently eccentric strength tests), is reliable and commonly used clinically due to its low cost and portability.[10, 53] Despite exploration of shoulder strength in swimmers in the literature over more than 20 years, results lack utility for clinicians due to inability to access isokinetic equipment and the lack of normative data for pain free swimmers.[5, 20, 21, 36, 37, 87] In the assessment of swimmers, the clinical utility of the HHD would be enhanced through the establishment of norms specific to this sporting population.

Shoulder strength ratios

The balance of muscle strength between agonist and antagonist groups around the shoulder have commonly been reported as muscle strength ratios. Shoulder IR and ER strength ratios (IR:ER or ER:IR) have been widely investigated in the sporting literature, reflective of the importance of the rotator cuff muscle group in maintaining stability around the glenohumeral joint.[88, 89] Despite a variety of testing protocols, there is a consensus that a shoulder strength ratio range from approximately 1:1-3:2 for IR:ER, is representative of a normal shoulder within the general population and some sporting populations.[89, 90] Strength ratios for IR:ER have been reported for throwers, tennis players, handballers and swimmers, with the optimal shoulder strength ratio a likely positive adaptation achieved over time, specific to the sport.[20, 41, 42] There is clear evidence for the throwing population, supporting an association between shoulder injury and reduced ER strength with an increased strength ratio for IR:ER.[41] Consequently, recommendations have been made to monitor throwers' strength ratios, comparing in season and preseason values.[41, 66] Preventative management would aim to address any deficits with appropriate strengthening exercises to normalise muscle balance.

Investigations, specific to the swimming population have produced variable results for IR:ER muscle strength ratios measured in swimmers with and without shoulder pain (**Table 2.3**). Generally, it is well supported that IR strength for the swimming population is greater than ER strength and greater overall compared to the general population.[19, 20] This bias towards increased IR strength is reflective of the IR action in freestyle swimming, the dominant training stroke for swimmers. However, the range of shoulder IR:ER strength ratios within the swimming population is large (**Table 2.3**), varying from 0.93 to 1.82.[20, 36, 37, 87] A variety of testing protocols using HHD and IKD on diverse and small populations (some with shoulder pain) may explain these varied results. From the studies that explored a correlation between pain and IR:ER strength ratio, (**Table 2.3**) three found no correlation[3, 18, 37] and one study concluded there was a relationship[36] although the sample size for all of these studies was small (n<38).

Compensatory strength programs have been recommended to address muscle strength imbalances in swimmers.[5, 20, 21, 36] However, such recommendations theorise that restoring muscle balance may reduce shoulder injury risk, without evidence of shoulder muscle imbalance being a causative factor for shoulder pain in swimmers. A change in shoulder muscle strength and strength ratio for the swimmer may be adaptive and advantageous. Indeed, what is the optimal IR:ER strength ratio for the young swimmer and when should a strength imbalance be addressed? Until functionally relevant, strength parameters specific to the young swimmer are generated, in the absence pain, strength intervention programs may be premature and misdirected.

Table 2.3 *Review of studies examining IR:ER shoulder muscle strength ratios in swimmers*

Author	Population (± pain)	No of male:female participants (age: range or mean in years)	Assessment protocol		ER:IR Outcomes		Summary of findings
			Tool; Mode	Test and shoulder position			
Beach et al. 1992 [37]	University (± pain)	8m:24f (15-21)	Isokinetic 60°/s	Prone Abd 90°	**Right shoulder** 1.43	**Left shoulder** 1.41	No correlation IR:ER with pain
McMaster et al.1992 [19]	National	14m:13f (18.5-20)	Isokinetic 30°/s	Standing (neutral)	**Males** 1.82	**Females** 1.56	↑ IR:ER compared to controls
Rupp et al. 1995 [18]	National (± pain)	10m:12f (14-26)	Isokinetic 60°/s	Supine Abd 90°	**Right shoulder** 1.32	**Left shoulder** 1.47	No correlation IR:ER with pain, sex, side or injury history
Bak et al. 1997 [36]	National (± pain)	9m:6f (15-25)	Isokinetic 30°/s	Sitting Abd 80°	**Pain free side** Conc 1.28 Ecc 1.28 Functional 1.12	**Pain side** 1.20 1.41 0.93	↓ IR:ER ratios for pain side
Ramsi et al. 2004 [20]	High school (no pain)	13m:14f (14-18)	HHD make test	Prone Abd 90°	**Males** 1.11	**Females** 1.10	post season values ↑ IR:ER ratios (↑ IR without equal gains in ER strength)
Batalha 2012 [87]	High school males (no pain)	60m (14.55 ±0.5)	Isokinetic 60°/s	Sitting Abd 90°	**Dominant** 1.36	**Non-dominant** 1.28	Normative Isokinetic data
Harrington et al. 2014 [3]	College females (±pain)	37f (19.5 ±1.2)	HHD NS	Supine	**Pain free side** 1.25	**Pain side** 1.25	*No differences between groups with and without shoulder pain

Abbreviations: Abd, abduction; Con, concentric; Ecc, eccentric; ER, external rotation; f, females; HHD, hand-held dynamometer; IR, internal rotation; m, males; NS, not stated; ↑ increase; ↓ decrease

Table 2.4 *Shoulder IR and ER normative strength values measured isometrically with a hand-held dynamometer*

Author	Population	Assessment protocol		IR Strength				ER Strength				Notes
	No of male:female participants (age: range or mean years)	**Test Mode**	**Test: shoulder position**	**Dominant**		**Non-dominant**		**Dominant**		**Non-dominant**		
				Males	Females	Males	Females	Males	Females	Males	Females	
Ramsi et al. 2004 [20]	High school swimmers 13m:14f (14-18)	make	Prone: abd 90°	42.3	30.5	39.3	29.5	37.7	27.7	36.0	26.8	Strength in lbs; post season; ICC NS
Riemann et al. 2010 [89]	Sample of convenience 90m:91f (18-40: 23.3)	make	Sitting: neutral	21.1	12.4	21.3	12.0	17.8	9.9	17.4	9.6	ICC (0.70-0.94)
			Prone: abd 90°	21.6	11.6	21.3	10.9	18.7	10.8	18.7	10.2	
Westrick et al., 2013 [91]	University 546m:73f (18.8 ±1.0)	make	Sitting: neutral	27	21	27	21	20	16	19	15	ICC (0.63-0.99)
			Supine: abd 45°	26	21	25	20	22	18	22	18	
Harrington et al. 2014 [3]	College female swimmers 37 (19.5 ±1.2)	NS	Supine: neutral		19				15			ICC (0.72-0.99)
Harlinger et al., 2015 [92]	Sample of convenience 10m:10f (20-24)	break	Sitting: neutral	10.1	5.7	8.0	4.7	10	6.3	8.0	5.9	Strength in kg ICC NS

Abbreviations: Abd, abduction; ER external rotation; f, female; kg, kilograms; ICC, intra-class correlation coefficient; IR internal rotation; m, male; NS, not stated; ↑ increase; ↓decrease

2.5.1 Measurement of Shoulder Strength

Several techniques and protocols using IKD and HHD have been used in research and clinically to test different modes of shoulder strength.[10] Regardless of the chosen strength-testing device, it is most important that the test protocol is reliable and reproducible to be clinically useful. Factors to consider in strength testing include: the position of subject and limb, the type or mode of test employed, level of training of the tester, reliability and the availability of normative data.[89, 93]

Test position

The reliability and outcomes of shoulder strength tests can be influenced by the position chosen for testing. This was clearly demonstrated when isokinetic strength values for shoulder rotation were assessed in three different positions (sitting, standing and supine).[94] Peak torque values for shoulder IR were higher in the seated position compared to the supine position, while the opposite was true for ER, which tested stronger in the supine position. This could be due to the activation of other muscle groups, such as trunk flexors, to assist trunk stability, particularly, in unsupported sitting. The authors concluded that supine lying with the arm abducted in the frontal plane was the most reliable test position for shoulder rotation. Similarly, following a series of reliability tests using the HHD for shoulder strength testing, although all test positions (sitting, supine and prone) demonstrated good to excellent reliability (ICC 0.93-0.99), the supine position was recommended.[17] In contrast to these findings, a systematic review of 16 studies that assessed the isokinetic strength of shoulder rotation, concluded that sitting was the most reliable test position.[95] It should be noted that in several of these investigations, subjects were strapped into the seated position, providing stability and increasing the isokinetic test reliability.

In addition to body position, the position of the shoulder during strength testing may influence reliability and strength outcomes. There is a consensus in the literature for good reliability of shoulder strength tests (ICC>0.87) despite shoulder test position; however, strength outcomes are not comparable.[9, 17, 96] Shoulder rotation strength outcomes have been compared when tested in neutral and in 90° shoulder abduction with varied results.[17, 89] In 90° shoulder abduction, ER strength was greater compared to when tested in the neutral position; however, the strength outcomes were greater for IR strength when tested in a neutral shoulder position (for females only).[89] These varied results are to be expected due to changes in muscle length tension relationships, capsuloligament tension and moment arm force which are associated with a change in shoulder position.

There is a need for functional strength testing in shoulder positions specific to swimming. Most shoulder strength studies, although reporting high reliability, have been performed in positions at or below 90° shoulder abduction, leaving gaps in our knowledge of the performance of strength tests in elevated shoulder positions.[9, 17, 89] For the swimmer, engaged in repeated overhead movements, functional shoulder tests include positions above 90° of shoulder elevation. To date, only one study has tested shoulder FL strength in elevation.[91] Shoulder FL strength was assessed in 135° shoulder abduction, with good reliability (ICC>0.83) reported for active college-age males and females. The assessment of swimmers' shoulder strength in positions above 90° shoulder elevation is highly relevant to function and provides direction for treatment and prevention programs.

Test mode

Isokinetic testing

Isokinetic strength testing has been viewed in the literature as the gold standard method in achieving an objective strength measurement.[10, 95] Despite undisputed high reliability, limitations such as large and expensive equipment, time-consuming set up and variable protocols, have limited the use of IKD clinically. The advantage of IKD over other methods of testing is the ability to measure eccentric and concentric strength modes, speed of contraction and endurance throughout range. However, due to the many variables that can affect isokinetic strength results, such as velocity, joint position, equipment and test position, it is difficult to compare current isokinetic strength studies, for the normal population and swimming cohort.[18, 19, 37, 88]

Hand-held dynamometer

The HHD, introduced in 1949, is a smaller, less expensive alternative for objective measurement of isometric muscle strength. This method of testing is commonly used in the clinic and has favourable outcomes in the literature for both validity and reliability tests, particularly in testing shoulder strength.[9, 10, 97, 98]

The use of a *make* or *break* test using a HHD has an influence on strength test results.[99, 100] A *make* test requires the tester to maintain a stationary test plate and match the maximum force provided by the subject. A *break* test is defined by the tester overcoming or breaking the maximal test force provided by the subject to move the limb out of the position tested.[99, 100] Higher reliability has been documented for the *make* test, while the *break* test can generate a greater force which requires a tester strong enough to overcome the *break* force.[99, 100]

Tester factors

The first landmark study on the reliability of the HHD reported that the HHD is a reliable strength testing tool when used by an experienced clinician and this has been supported more recently in a systematic review.[10, 97] In these studies the experienced tester was consistent in positioning the HHD at an angle perpendicular to the tested limb, in the same location for each test so factors affecting muscle force production such as lever arm length, muscle length and joint angle remain stable. To enhance reliability, the tester's body should be held in position that is stable and ready to brace matching the force provided by the subject without any movement of the HHD or tested limb.[98]

The strength and size of the tester using a HHD have also been suggested to influence the reliability of the HHD.[10, 101] Strength tests for the upper and lower limb from three testers of different size and strength determined that tester strength appeared to be a major determinant of the magnitude and reliability of the forces measured with a HHD.[101] Results were consistent and reliable for shoulder ER and elbow FL strength tests, even for the weaker testers.[101] In addition to tester strength, the effects of related factors such as female gender, lower BW and reduced grip strength have been suggested to compromise the reliability of HHD strength measurements.[24]. However, investigations using the HHD to test the upper limb have consistently demonstrated fair to excellent inter and intra-rater reliability, with tester training and years of experience increasing the reliability of HHD testing.[9, 10, 93, 98] Thus, rather than size, the experience of the tester is clearly a more important factor contributing to shoulder strength test reliability.

Comparable reliability

Although IKD has been considered the gold standard of strength testing, a systematic review, which included 14 studies suggested that HHD is a reliable and valid method of performing strength testing in the clinical situation.[10] Furthermore, results favouring the reliability of the HHD over IKD were reported by Tyler[102] who demonstrated that using a HHD to perform muscle testing might reveal shoulder strength deficits that are not apparent with isokinetic testing.

2.5.2 Normative Data

Normative strength data is necessary to provide objective strength parameters, which allow evaluation and monitoring of deficits and inform clinical decision-making. Normative shoulder strength data must be population and apparatus specific, with measures normalised to BW to allow for comparison between individuals of different size and structure. There is limited information regarding normative values for swimmers' shoulder strength using IKD. One study, reported normative shoulder strength values for male swimmers only but these results were not normalised to BW, making clinical comparison from this data base challenging.[87]

As the HHD is commonly used clinically, baseline shoulder strength values have been generated in the literature, some normalised to BW, increasing their clinical utility (**Table 2.4**). Two studies with a large general population sample size, established IR and ER shoulder strength values using a HHD, which are included in **Table 2.4**.[89, 91] In addition, shoulder IR and ER strength values, specific to swimmers (**Table 2.4**) have been reported in two studies, with a smaller sample size (n<38).[3, 20] However, swimmer specific, normative shoulder strength data relative to BW is lacking. The establishment of such a data set, which is both functional with respect to shoulder position and specific to swimmers, will provide a valuable comparative guide for clinicians treating swimmers with shoulder pain.

In summary, to generate clinically useful data for swimmers' shoulder strength, a clearly described and reliable protocol should be employed, with results normalised to BW. After reviewing the literature, the following evidence-based shoulder strength testing protocol is recommended: an experienced tester performing an isometric *make* test using a HHD, with the subject stable and upper limb in an elevated position. For shoulder strength testing, the reliability of a tester should not be limited by their size or strength provided the tester is experienced in using a HHD.

2.6 Scapular Position

Optimal positioning of the scapula is required during shoulder elevation to provide an essential link allowing the transfer of energy from the body to the moving arm. Full range of shoulder elevation is essential for swimmers and must be accompanied by adequate, coordinated scapular rotation around three axes to posteriorly tilt, and externally and upwardly rotate the scapula, essentially coupling arm and shoulder movement.[54, 103] This scapular positioning facilitates elevation of the acromion, centralisation of the humeral head and optimisation of the length-tension relationship of the rotator cuff muscles to ensure optimal function of the shoulder. Hence, an understanding of scapular position in the swimmer is valuable and may be included in a clinical shoulder assessment.

2.6.1 Measurement

Scapular position, has been assessed clinically, using simple observation, tape measures and inclinometers; and in the laboratory situation, using electromagnetic motion sensors.[11, 104] Simple observation and a subjective yes/no assessment for abnormal scapular position has been used but not in static positions above 90° shoulder abduction which are functional to swimmers.[11, 104] While 3-dimensional electromagnetic assessment is a valid and reliable scapular assessment technique, ideal for the laboratory situation, it is not practical in the clinic.[22, 105]

Scapular UR contributes the largest amount of scapular rotation (40-50º, compared to posterior tilt: 21-30º and ER: 2-24º when the arm is elevated) and is currently the only scapular movement and position that can be reliably measured in the clinic.[14, 16] Using inclinometers, good to excellent *within session* reliability (ICC 0.89-0.92) has been reported for the measurement of scapular UR, in populations with or without shoulder pain (**Table 2.5**). On this basis, the simple and affordable clinical assessment tool has been recommended in the clinical assessment of scapular UR.[11] The inclinometer is placed along the spine of the scapular and the degree of scapular UR can be measured in various degrees of shoulder abduction in the coronal or scapular plane (30° anterior to the frontal plane).[11] Despite large ranges reported, good reliability has been reported in shoulder abduction up to 135° (ICC 0.81), making it a useful clinical tool for measuring scapular UR in shoulder positions that are functional for the swimmer.

Table 2.5 *Review of studies examining scapular position measurements and reliability*

Author	Population: male; female participants (age: range or mean years)	Assessment protocol/tool	Shoulder positions examined	Reliability or outcomes		Summary of findings
				Intertester	Intratester	
Johnson, G et al. 1993 [106]	16m no pain (18-60)	Scapular tilt, protraction and elevation with 3D electromagnetic movement sensor (Isotrack)	Seated; 0°, 55°, 90° &120° shoulder abd in coronal plane	Large observer variation: 1.8-5.7° difference in scapular tilt & for protraction - 3.3-2.4°	F significant in all cases (p<0.05)	Difficulty contacting acromion reliably in out of plane angles but useful clinically
Johnson, M et al. 2001 [16]	Sample of convenience 39m; 16f with shoulder pathology (35)	UR measured statically with modified digital inclinometer placed along spine of scapula compared to 3D magnetic tracking device	Standing Static: rest, 60°, 90°, 120° shoulder abd in scapular plane	For intratester reliability: ICC 0.89-0.96 (highest at 120° shoulder abd) For validity: Pearson r ranged from 0.74-0.92 for inclinometer compared to static magnetic tracking measures		Good to excellent intratester reliability and validity for modified inclinometer (within session)
Borsa et al., 2003 [73]	5m; 5f no pain (20.4 ±2.4)	UR measured statically with modified digital inclinometer placed along spine of scapula	Standing; rest, 30°, 60°, 90°, 120° shoulder abd in coronal and scapular plane	Between session intratester reliability: ICC 0.56-0.94 Within session intratester reliability: ICC 0.97-0.99		Between session (1 week) poor to excellent reliability
Watson et al. 2005 [14]	Patients with various shoulder pathology 11m; 15f (29)	UR measured statically with Plurimeter-V gravity inclinometer placed along spine of scapula	Standing Static: rest, 45°, 90°, 135° shoulder abd in coronal plane	One tester only	SEM ranged from 1.7-5.2°; ICC 0.81-0.94; large ranges eg. 25-75° at 135° abd	Very good intratester reliability overall, can be used effectively and reliably for measuring UR of scapular in coronal plane (within session)

Abbreviations: Abd, abduction; f, females; ICC, intraclass coefficient variation; m, males; SEM, standard error of measurement; UR, upward rotation.

Table 2.6 *Review of studies comparing scapular position in populations with and without shoulder pain*

Author	Population: pain or no pain (age: range or mean years)	Assessment protocol/tool / Scapular position alteration investigated	Shoulder positions examined	Outcomes	Summary of findings
Lukasiewicz 1999 [105]	17 with pain (45.8) 20 no pain (34.3)	3D electromechanical digitiser measured UR, posterior tilt, IR	Arm elevation in scapular plane	Less posterior tilt for subjects with pain (25°±9°) compared to without (35°±10°); & higher superior-inferior scapular position (5 ±2cm below first thoracic vertebrae compared to 8±2cm)	UR: no differences Posterior tilt: ↓ in pain group IR: no differences
Ludewig & Cook 2000 [107]	26 impingement pain 26 no pain (20-71)	Electromagnetic surface sensors UR, posterior tilt, IR	60°, 90°, 120° shoulder abd with & without load	Less scapular UR at 60° across all load conditions ($p<0.025$)	UR: ↓ in pain group Posterior tilt: ↓ in pain group IR: ↑ in pain group
Graichen 2001 [108]	20 pain 14 no pain	3D motion analysis of shoulder girdle & supraspinatus UR	30°, 90°, 120° shoulder abd	No significant differences between pain & no pain group or healthy shoulder & pain shoulder in the pain group ($p<0.05$). 5 demonstrated increased glenoid UR 2 SD above the control group.	No differences but a subset of patients with pain demonstrated changes in shoulder girdle movement
Su et al. 2004 [13]	Swimmers 9m; 11f with SIS (24.2) 10m; 10f no pain (23.6)	measured with inclinometer pre & post swim training UR	Rest, 45°, 90° & 135° shoulder abd	Prior to swim practise scapular position was the same ($p=0.20$); after swim, difference in scapular elevation angle ($p=0.008$); although clinically small <5°	No differences in baseline measures pre-swim UR ↓ post training swim for pain group
McClure 2006 [52]	24m; 21f with pain (45.2) 24m; 21f no pain (43.6)	3D electromagnetic motion analysis UR, posterior tilt, ER	Through range flexion, abd & rotation	In shoulder flexion & abd greater posterior tilt & UR of scapula (p=0.018 & 0.002); no differences found for ER	UR: ↑ in pain group Posterior tilt ↑ in pain group ER: no differences

Abbreviations: Abd, abduction; ER, external rotation; f, females; ICC, intra-class coefficient variation; IR, internal rotation; m, males; SEM, standard error of measurement; SD, standard deviation; SIS, shoulder impingement syndrome; UR, upward rotation.

2.6.2 Changes in Scapular Position

Changes in scapular position, have been suggested as factors associated with and possibly contributing to shoulder pain in the general population[52, 107, 109] and swimmers.[13, 49] In particular, scapular UR, essential for arm elevation, and therefore in swimming, may change in the presence of shoulder pain. However, reports including both the general population and swimmers are conflicting and the direction and amount of change in scapular UR is inconclusive. Reports of increased[52], decreased[107] and no differences in scapular UR have been reported in general population cohorts with shoulder pain compared to pain-free shoulders (**Table 2.6**).[105] More recently, meta-analyses of comparative studies[110] established that patients with shoulder subacromial impingement syndrome demonstrated less scapular UR.

Differences in scapular UR have also been postulated within swimming cohorts and may be influenced by pain. Less scapular UR was reported on the symptomatic side for swimmers with shoulder pain, compared to the non-painful side and compared to a swimming group without shoulder pain.[13] Both groups were pain-free and had similar degrees of scapular UR before a swim training session so the differences were found only after swim training when pain was experienced. However, the difference between groups was clinically small (2-3°) and may be implicated by a large variability in scapular measurements. It is feasible that shoulder pain may influence scapular UR position in different ways and further investigation is required. Normative data for scapular UR in pain-free swimmers will help in providing baseline measures to use as a reference point within the sport.

Given that, changes in scapular UR have been associated with shoulder pain in the general population and swimmers, knowledge of what constitutes normal scapular UR would be useful in the management of shoulder pain.[13, 47, 111] Clinicians often use side-to-side comparison of scapular position in a shoulder assessment; however, such comparison is based on an assumption of symmetry and scapular symmetry varies within the pain-free population.[112, 113] Scapular UR asymmetry is expected in unilateral overhead athletes, with the dominant arm demonstrating decreased scapular UR compared to the non-dominant side[43] but it is unknown if scapular symmetry is a normal expectation for the swimming athlete.

Developing our knowledge of scapular UR in swimmers would help to establish whether a side-to-side comparison is useful and to determine any potential association with shoulder pain. Current data for the assessment of scapular UR is variable so it is unclear if this factor is a means on which to base clinical decision-making, treatment and prevention programs. Consequently, scapular UR measurement in swimmers is an area worthy of further investigation.

Normative data

Various objective measures are used in the assessment of swimmers presenting with shoulder pain, yet normal parameters for the young swimming population are scarce. Due to these gaps in the literature, clinicians lack useful assessment parameters and direction for effective treatment and prevention programs for this sporting group. Normative data can provide a reference point for assessment, identify deficits, inform clinicians' decision-making and provide justification for interventions. Measures that can be reproduced in the clinical situation using reliable and easily accessible tools are most useful. Moreover, the establishment of normative data stratified to the young swimmer is paramount to define risk factors for shoulder pain.

2.7 Conclusion

Shoulder strength and scapular UR are modifiable physical factors commonly assessed by clinicians treating swimmers with shoulder pain; however, their associative and predictive value for shoulder pain are unclear. Valid and reliable measurements of shoulder strength and scapular UR can be performed using a HHD and an inclinometer, clinical tools that are both affordable and portable. Consequently, the establishment of normative data, using protocols which can be reproduced in the clinic, is essential to further an understanding of the relationship of shoulder strength and scapular UR with the development of shoulder pain. Such normative data needs to be stratified for age, arm dominance, gender and BW. However, there is a paucity of normative measures and few studies have used clinically applicable methodology involving swimmers. Previous investigations performed on swimmers in the presence of shoulder pain have produced mixed findings and prospective follow up is scarce. Therefore, research addressing these gaps in the literature will help to understand and identify if shoulder strength and scapular UR are in fact potential risk factors for the development of shoulder pain in young swimmers.

The research presented in this thesis aimed to employ methodology that can be easily reproduced in the clinic using a HHD and an inclinometer to establish normative data for shoulder strength and scapular UR in functional shoulder positions for swimmers who may have had previous shoulder pain but were without current pain. This data formed the basis for a longitudinal study by means of a follow up survey of tested swimmers, which investigated the influence of a previous history of shoulder pain, relative shoulder strength, shoulder strength ratios and scapular UR on the development of shoulder pain in swimmers.

Chapter 3. The reliability of strength tests performed in elevated shoulder positions using a hand-held dynamometer.

An original version of this chapter has been published in the Journal of Sport Rehabilitation as an original technical report and appears in the literature as:

McLaine SJ, Ginn KA, Kitic CM, Fell JW and Bird M-L. The reliability of strength tests performed in elevated shoulder positions using a hand-held dynamometer. *Journal of Sport Rehabilitation.* 2016, epub. http://dx.doi.org/10.1123/jsr.2015-0034

Journal Impact Factor: 1.413

Minor formatting changes for the purpose of inclusion into this thesis have been made to the original accepted version of this manuscript.

Rationale

The reliability of isometric shoulder strength tests using a HHD in positions at or below shoulder level has been well documented. However, it was important to establish reliability of a protocol where a single clinician tested shoulder strength in elevated shoulder positions without the application of external support, which would require a second clinician, not a clinically feasible scenario. It was also important to compare testing positions and determine if one was more reliable or easier for the tester to perform strength testing. This would form the basis of the testing protocol for normative data collection for shoulder strength tests performed in elevated shoulder positions.

3.1 Abstract

*Context***:** The reliable measurement of shoulder strength is important when assessing the athlete involved in overhead activities. Swimmers' shoulders are subject to repetitive humeral elevation and consequently have a high risk of developing movement control issues and pain. Shoulder strength tests performed in positions of elevation assist with the detection of strength deficits that may impact on injury and performance. The reliability of isometric strength tests performed in positions of humeral elevation without manual stabilisation, which is a typical clinical scenario has not been established.

Objective: To establish the relative and absolute intra-rater reliability of shoulder strength tests functional to swimming in three body positions commonly used in the clinical setting. *Design***:** Repeated measures, reliability study. *Setting:* Research laboratory. *Subjects:* Fifteen university students and staff (mean ± SD age 24 ± 8.2 y) volunteered for the study. *Intervention:* Isometric shoulder strength tests were performed in positions of humeral elevation (flexion and extension in 140° abduction in the scapular plane; internal and external rotation in 90° abduction) on subjects without shoulder pain in supine, prone and sitting. Subjects were tested by one examiner with a hand-held dynamometer and retested after 48 hours. *Main Outcome Measures:* Relative reliability ($ICC_{3,1}$) values with 95% CI. Absolute reliability was reported by minimal detectable change (MDC). *Results:* Good to excellent intra-rater reliability was found for all shoulder strength tests (ICC 0.87-0.99). Intra-rater reliability was not affected by body position. MDC% was less than 15% for every test and less than or equal to 11% for tests performed in supine. *Conclusions:* Shoulder flexion, extension, internal and external rotation strength tests performed in humeral elevation demonstrated excellent to good intra-rater reliability regardless of body position. A strength change of more than 15% in any position can be considered meaningful.

Keywords: isometric contraction, muscle strength dynamometer, shoulder joint

3.2 Introduction

The reliable measurement of an athlete's shoulder strength is an important part of clinical assessment. Accurate shoulder strength assessment and measurement of strength change over time is necessary when making clinical decisions concerning diagnosis, treatment, exercise progression, training loads and in sport specific screening. In order to determine specific shoulder strength deficits related to an athlete's overhead function, assessment should include tests in elevated positions of the humerus at and above 90° shoulder abduction.

In the early pull-through phase of the freestyle swimming stroke may reach end range abduction and shoulder pain is commonly reported[6, 7] hence the reliable investigation of possible contributing factors, such as shoulder muscle weakness,[86, 114] is paramount. Flexion (FL) and extension (EX) strength tests in 140° abduction are functionally relevant to this part of the stroke and the hand-entry phase. Another vulnerable part of the stroke is recovery when the arm is out of the water and the shoulder is moving into abduction and external rotation (ER), where pain and impingement has been reported to occur.[6, 7]

Previous research has demonstrated that shoulder ER, internal rotation (IR), abduction, adduction, FL and EX strength testing using a hand-held dynamometer (HHD) is reliable in ranges at or below shoulder height,[9, 10, 17] however, no studies have investigated shoulder FL and EX in ranges above 90° abduction. Body position has been shown to influence the reliability of strength testing. Cools et al.[17] demonstrated good to excellent reliability for shoulder rotation strength tests regardless of patient position with stabilisation provided to the trunk or limb which is not always possible for the sole clinician.

This study aimed to establish the relative and absolute intra-rater reliability for testing shoulder (FL and EX in 140° abduction; ER and IR at 90° abduction) strength in different body positions without external stabilisation.

3.3 Methods

Design: A repeated-measures reliability study design was used. Independent variables were examiner, tests and body position. The dependent variable was muscle strength (Newtons).

Subjects: Volunteers between the ages of 18-30 yrs were recruited from the university community. Exclusion criteria were a history of: shoulder dislocation or surgery and shoulder pain within the previous two months. Potential subjects were excluded if shoulder pain was experienced during the testing procedure. Permission to conduct this research was granted by the university's ethical committee. *Procedures:* One experienced female physiotherapist (weight, 56kg) performed the measurements. The tester was blinded during testing. Tests were performed using the self-calibrating JTech PowerTrack™ Commander Muscle Tester (JTECH Medical, Salt Lake City, Utah, USA).

Shoulder FL, EX, ER and IR strength tests were performed bilaterally in prone, supine and sitting positions on two occasions, 48 hours apart. The order of testing was block randomised. Within each test position (prone, supine and sitting), shoulder strength tests (ER, IR, FL and EX) and side of testing were randomised for each subject. The same order for shoulder ER and IR (**Figure 3.1A**), and FL and EX (**Figure 3.1B**) strength tests was used for both sessions. No manual stabilisation was provided to the participant's body or upper limb.

Figure 3.1 *Measurement of shoulder strength performed in sitting, supine and prone.*
A. *External rotation.* **B.** *Flexion.*

Subjects completed a questionnaire which included questions on hand dominance, shoulder injury, pain and exercise frequency. A three-minute shoulder warm-up was performed with resistance tubing in the same directions used for testing.

A *make* strength test was performed for each of the test positions. Two repetitions of each strength test were performed in each test position with a rest period of five seconds between each repetition and 30 seconds between each strength test. The subject was asked to gradually build up to a maximum force and maintain the effort, then relax after five seconds.

Statistical Analyses: The maximum value recorded from the two repetitions of each test session was used for analysis. The overall mean (M) and standard deviation (SD) in Newtons (N) were calculated for each strength test in each body position. Test-retest intraclass correlation coefficients (two-way mixed with absolute agreement) $ICC_{3,1}$[115] and associated 95% confidence intervals (CI) were calculated after normality of data were determined using the Kolmogorov-Smirnov test. Reliability was reported as excellent (ICC $\geq$0.90), good (ICC between 0.80 and 0.89), moderate (ICC between 0.70 and 0.79) and low (ICC<0.70).[116]

To determine absolute reliability i.e. the extent to which the measurement varied for subjects between the two testing sessions, the standard error of measurement (SEM) was calculated. The SEM value was used to calculate the minimal detectable change (MDC) at the 90% CI. To enable more meaningful comparison between different individuals and tests, %MDC was then calculated. All data analyses were performed with SPSS (Version 20, IBM Corp, Armonk, NY, USA).

3.4 Results

Fifteen subjects: age 24 (± 8.2) yrs; height 169 (± 3.4) cm; weight 66 (± 10.4) kg completed all tests with no reports of shoulder pain during testing. Ten subjects were female, two were left-handed, three had a history of previous injury (more than 12 months before testing) and 13 participated in structured physical activity at least three times per week.

Good reliability was demonstrated for all FL and EX tests (ICC 0.87-0.99) (**Table 3.1**). All rotation tests demonstrated excellent reliability (ICC 0.90-0.99) (**Table 3.2**). The MDC_{90}

ranged from an absolute 1.81 to 13.41 N for all strength tests with %MDC consistently below or equal to 15% (**Table 3.1** and **Table 3.2**).

3.4 Discussion

This is the first investigation to report the reliability of shoulder FL and EX strength tests above 90° shoulder abduction in three different positions. Intra-rater reliability for FL and EX tests was good in all positions. (ICC 0.87-0.99) (**Table 3.1**). These more than acceptable intra-rater reliability results were achieved without the application of any external stabilisation to the upper limb or trunk and with tests performed on different days, replicating a typical clinical scenario.

Excellent intra-rater reliability was also demonstrated for ER and IR strength tests performed in 90° shoulder abduction in all three body positions, without external or manual stabilisation and MDC results remained below 14% for all tests (**Table 3.2**). These results are comparable to previously described intra-rater ICC values (0.93-0.99) for ER and IR strength tested at 90º abduction [17] and indicate that ER and IR shoulder strength can be measured in elevated ranges as reliably as reported in lower ranges[9, 93] when external stabilisation was provided.[9, 17, 93] Although %MDC values have not been previously reported for shoulder rotation strength tests, the MDC values for ER and IR strength measured in this study are comparable to those previously reported at 90° abduction (10.7 to 16.8)[17] and 0° abduction (8.7-10.6N)[9] (**Table 3.2**). Previous studies performed retesting on the same day, while the current study protocol retested after 48 hours, a common clinical situation.

These results indicate that for shoulder FL, EX and rotation strength tests performed in an elevated position in any of the three body positions, a change of more than 15% is likely to be a true change in strength, rather than a difference due to measurement error. The supine position is recommended if performing all tests as a group as the %MDC values remained below 12% and it is ergonomic for the tester. The MDC remained below 6% for all rotation tests performed in prone hence this position is preferable for the rotation tests.

The good to excellent intra-rater reliability and %MDC results demonstrated in this study have significant implications for the clinician assessing and treating athletes. As many overhead athletes, including swimmers, experience shoulder pain when the arm is above shoulder height,[6, 7] a reliable functional strength assessment in this range is required. To assess the effectiveness of strengthening exercises to restore function, optimise performance and prevent injury, changes need to be measured over time often by a single clinician. The results of this study have demonstrated that such a strength assessment can be performed reliably without external stabilisation, benefiting the sole clinician, and thus is an accurate and efficient method that can be easily translated into busy clinical schedules. Furthermore, establishing the %MDC which represents meaningful change in shoulder strength enables clinicians to accurately evaluate the effectiveness of strengthening programs.

The intra-rater reliability achieved in this study was aided by a number of factors. It has been established that the strength of the tester affects his/her ability to stabilise a HHD, and therefore, influences the reliability of measurements.[10, 93] Consequently, the strength testing protocols were designed to give a mechanical advantage to the tester by employing optimal tester positioning and maximising the length of the lever arm in all tests. In addition, careful and consistent HHD and subject positioning, clear instructions to subjects and familiarisation with the tests by incorporating these as the warm-up movements are likely to have contributed to the reliability results achieved.

The results of this study only apply to a single tester and the inter-tester reliability of shoulder strength tests in elevated shoulder positions remains to be established. However, the encouraging intra-rater reliability results achieved show promise that a reliable, functionally relevant shoulder strength testing protocol for the swimming population and other overhead athletes is achievable. Future research will determine if this predication is accurate.

Table 3.1 *Intra-rater reliability of flexion and extension shoulder strength tests for sitting, supine and prone positions.*

Test	Position	Test1 (N)	Test2 (N)	ICC (95% CI)	SEM (N)	MDC_{90}(N)	%MDC
FL DOM	Sitting	46.6 (18.6)	48.4 (16.9)	0.94 (0.82-0.98)	2.15	5.02	10.57
	Supine	64.4 (24.6)	60.5 (22.3)	0.94 (0.82-0.98)	2.76	6.43	10.30
	Prone	36.7 (8.6)	35.8 (10.6)	0.87 (0.62-0.96)	2.38	5.54	15.30
FL NON	Sitting	45.3 (15.1)	45.3 (18.7)	0.93 (0.78-0.98)	2.70	6.30	13.90
	Supine	61.3 (21.8)	60.7 (21.0)	0.94 (0.81-0.98)	2.67	6.21	10.19
	Prone	35.5 (10.7)	35.9 (11.1)	0.93 (0.79-0.98)	1.51	3.53	9.87
EX DOM	Sitting	59.2 (25.4)	62.0 (22.5)	0.96 (0.88-0.99)	1.86	4.34	7.15
	Supine	73.2 (42.5)	71.7 (41.3)	0.98 (0.94-0.99)	1.74	4.05	5.59
	Prone	79.1 (41.1)	79.7 (36.9)	0.98 (0.95-0.99)	1.51	3.52	4.43
EX NON	Sitting	60.8 (32.2)	60.6 (28.6)	0.97 (0.90-0.99)	1.91	4.45	7.34
	Supine	74.9 (40.7)	74.7 (39.8)	0.96 (0.87-0.99)	3.53	8.25	11.02
	Prone	77.0 (35.1)	78.1 (37.5)	0.99 (0.97-0.99)	0.78	1.82	2.34

Abbreviations: CI, confidence interval; DOM, dominant side; EX, extension; FL, flexion; ICC, Intraclass Correlation Coefficient; MDC, minimal detectable change; N, newtons; NON, non-dominant side; SEM, standard error of measurement.

Table 3.2 *Intra-rater reliability of external and internal rotation shoulder strength tests for sitting, supine and prone positions.*

Test	Position	Test1 (N)	Test2 (N)	ICC (95% CI)	SEM (N)	MDC_{90}(N)	%MDC
ER DOM	Sitting	93.7 (37.2)	87.1 (33.7)	0.97 (0.88-0.99)	1.79	4.17	4.61
	Supine	109.3 (43.6)	103.9 (35.2)	0.96 (0.87-0.99)	3.15	7.36	6.90
	Prone	103.8 (36.0)	96.7 (39.0)	0.95 (0.81-0.99)	3.31	7.73	3.54
ER NON	Sitting	94.2 (40.8)	90.9 (36.4)	0.97 (0.91-0.99)	2.36	5.51	5.96
	Supine	110.7 (38.7)	99.2 (33.5)	0.92 (0.68-0.97)	4.97	11.60	10.41
	Prone	103.8 (45.7)	97.4 (37.7)	0.96 (0.89-0.99)	2.99	6.98	3.26
IR DOM	Sitting	103.2 (34.8)	105.6 (39.7)	0.97 (0.90-0.96)	2.41	5.63	5.39
	Supine	100.1 (36.4)	100.6 (35.9)	0.93 (0.80-0.98)	4.90	11.42	10.28
	Prone	106.7 (50.3)	104.3 (41.9)	0.97 (0.90-0.99)	2.89	6.74	2.90
IR NON	Sitting	101.3 (38.6)	97.3 (28.2)	0.90 (0.70-0.97)	5.75	13.41	13.51
	Supine	101.8 (35.0)	102.1 (33.3)	0.97 (0.91-0.99)	2.13	4.97	4.88
	Prone	99.7 (43.7)	100.9 (39.5)	0.94 (0.82-0.98)	4.96	11.57	11.45

Abbreviations: CI, confidence interval; DOM, dominant side; EX, extension; FL, flexion; ICC, intraclass correlation coefficient; MDC,minimal detectable change; N, newtons; NON, non-dominant side; SEM, standard error of measurement.

Chapter 4. Isometric shoulder strength in young swimmers

An original version of this chapter has been published in the Journal of Sports Medicine and Science as an original research investigation and appears in the literature as:

McLaine SJ, Ginn KA, Fell JW and Bird M-L. Isometric strength profile of the young swimmer. *Journal of Science and Medicine in Sport.* 2017; 21(1):35-39.

Journal Impact Factor: 3.929

Minor formatting changes, for the purpose of inclusion into this thesis, have been made to the original accepted version of this manuscript.

Rationale

In the assessment of swimmers' shoulder strength, clinicians benefit from knowledge of strength measures with which to compare their outcomes and subsequently guide clinical decisions and interventions. Prior to this research, there were no published isometric shoulder strength normalised to BW. Using the strength testing protocol purposely established for clinical utility, shoulder IR, ER, FL and EX strength and strength ratio data have been established to help address this gap in the literature.

4.1 Abstract

Objectives: The prevalence of shoulder pain in young swimmers is high. Shoulder rotation strength and the ratio of internal to external rotation strength have been reported as potential modifiable risk factors associated with shoulder pain. However, relative strength measures in elevated positions, which include flexion and extension, have not been established for the young swimmer. The aim of this study was to establish clinically useful, normative shoulder strength measures and ratios for swimmers (14-20 yrs) without shoulder pain. *Design:* Cross-sectional, observational study *Methods:* Swimmers (N=85) without a recent history of shoulder pain underwent strength testing of shoulder flexion and extension (in 140° abduction); and internal and external rotation (in 90° abduction). Strength tests were performed in supine using a hand-held dynamometer and values normalised to BW. Descriptive statistics were calculated for strength and strength ratios (flexion:extension and internal:external rotation). Differences between groups (based on gender, history of pain, test and arm dominance) were explored using independent and paired *t* tests. *Results:* Normative shoulder strength values and ratios were established for young swimmers. There was a significant difference ($p<0.002$) in relative strength between males and females for all tests with no differences in strength ratios. Relative strength of the dominant and non-dominant shoulders (except for extension); and for swimmers with and without a history of shoulder pain was not significantly different. *Conclusions:* A normal shoulder strength profile for the young swimmer has been established which provides a valuable reference for the clinician assessing shoulder strength in this population.

Keywords: swimming, muscle strength dynamometer, isometric contraction, muscle strength, rotation, shoulder pain

4.2 Introduction

Shoulder pain is common in young swimmers and can impact performance in training and competition, possibly even terminating participation. Young swimmers (12-19 yrs) have been reported to have a high prevalence of shoulder pain (up to 41%)[5] and a strong history of pain.[28] Some of the factors that have been investigated and proposed to contribute to swimmers developing shoulder pain include shoulder muscle weakness, an imbalance between shoulder IR and ER muscle strength, training load and previous injury history.[5, 36, 51]

Increased swim training exposure and shoulder muscle strength imbalance are perhaps interrelated[20, 117] and frequently recognised as possible risk factors for the development of shoulder pain in swimmers.[5, 28, 36] A swimmer with reduced shoulder strength, or normal strength but muscle imbalance, may be at risk of injury.[4, 36] With freestyle being the dominant stroke used in training,[1, 51] swimmers' shoulders repeatedly move against force into IR, adduction and EX and increases in strength in these shoulder muscle groups could be expected. Indeed, IR and adduction strength have been reported to be greater in swimmers compared to the normal population, while ER strength values remained comparable and EX strength values are yet to be reported.[18, 19, 21] Selective increases in strength in the shoulder muscle groups generating the forces required for swimming can result in muscular imbalances over time.[20] The relationship between shoulder pain and shoulder rotation strength ratios has previously been investigated with conclusions inconsistent, reporting both increased and unchanged ratios of IR:ER in swimmers with shoulder pain compared to swimmers without shoulder pain.[5, 18, 36] Clearly, there are many factors to consider but the association of shoulder muscle strength balance and pain remains to be verified and further strength measures are warranted.

Reliable and easy to replicate shoulder strength tests functional to swimming strengthen validity and clinical utility. Assessment of the swimmer in elevated shoulder positions (shoulder abduction 90° and above) similar to the position of the shoulder at the hand-entry, early pull-through and recovery phases of the freestyle swim stroke, is highly relevant as shoulder pain and altered muscle function are reported in these positions.[86, 118] The reliability of shoulder strength tests performed in elevated ranges using a HHD, a clinically useful and portable tool, has been reported as good to excellent, providing scope for further investigation in these functional ranges.[9, 17, 119]

Limited normative data is available regarding shoulder strength parameters that can be used by the clinician when assessing the young swimmer. Knowledge of what constitutes “normal” shoulder strength for the young swimmer is important in establishing benchmarks that can be used in the clinic to recognise, monitor and manage swimmers with strength deficits who may be at risk of developing shoulder pain. Moreover, such measures must be stratified for age, gender and body size in order to identify significant deviations.[31] Establishing a normal strength profile for young swimmers using measures that can be easily replicated in a clinical setting will provide the clinician with a valid reference point for comparison. Therefore, the aims of this study were to establish relative (expressed as a percentage of BW, normative shoulder strength measures FL, EX, IR, ER and muscle strength ratios for young swimmers without shoulder pain using a HHD; and to compare shoulder strength measures and ratios (FL:EX and IR:ER) between males and females, dominant and non-dominant shoulders and participants with and without a history of shoulder pain.

4.3 Methods

Participants for this study included swimmers aged 14-20 yrs without current shoulder pain who trained at least six hours per week. Recruitment was initiated by a letter of invitation to participate via coaches of swimming clubs (**Appendix E**). The letter was followed up with a meeting and explanation of the study to coaches, swimmers and their parents. Exclusion criteria included a history of shoulder dislocation, neck or shoulder surgery and recent shoulder pain over the past two months, which resulted in missing at least two swim training sessions. Potential participants were excluded if shoulder pain was reported during the testing procedure.

Prior to testing, swimmers (or parents/guardians if swimmer was under 18 yrs) completed a consent form (**Appendix G**) and questionnaire (**Appendix H**) which included questions on hand dominance (arm with which you throw), previous shoulder injury or pain, swim performance and training history. Permission to conduct this research was granted by the Tasmanian Health and Medical Human Research Ethics Committee of the University of Tasmania (H0012936).

Isometric shoulder strength tests were all performed in supine using a HHD: JTech PowerTrack™ Commander Muscle Tester (JTECH Medical, Salt Lake City, Utah, USA). The machine was factory calibrated and recalibrates each time it is turned on.

Shoulder FL and EX strength tests were performed at 140° shoulder abduction in the scapular plane (30° anterior to the frontal plane) with the elbow extended and the forearm pronated (**Figure 4.1A**). This elevated shoulder position is functionally relevant for the swimmer because it is similar to the shoulder position at the hand entry and early pull-through phase of the freestyle swim stroke. Full range elevation would replicate this phase more closely but was avoided to reduce the risk of potential pain provocation when using the same test on symptomatic swimmers in the future. For shoulder IR and ER strength tests the arm was positioned at 90° shoulder abduction, (functionally relevant to the mid pull-through and recovery phases) with the forearm vertical and the elbow flexed to 90° (**Figure 4.1B**). A goniometer was used to confirm correct arm abduction position for all tests. Swimmers were instructed to keep the trunk from moving during testing. Strength tests performed in the described shoulder positions without additional manual stabilisation to the trunk or upper limb have demonstrated excellent intra-rater reliability in supine.[119] In addition, the supine position provides comfort for the swimmer in the field setting (if monitoring strength poolside without a plinth the head can remain in neutral) and the tester has an ergonomic and mechanical advantage when testing (contributing to test reliability). The primary investigator, a Sports Physiotherapist with over eight years of experience using a HHD, performed all strength measurements.

Swimmers reported poolside for a single testing session before commencing normal swim training. The swimmer's weight was recorded. A computer-generated randomised order for strength tests (FL, EX, IR and ER) and side of testing was generated prior to testing. A three minute warm-up was performed using an elastic resistance tube in the same directions used for testing.

The distal edge of the HHD plate was positioned on a previously marked line level with the proximal aspect of the ulnar styloid process on the anterior and posterior aspect of the forearm. Swimmers were given instructions and a familiarisation session for each test at submaximal force ensuring that the correct action was performed prior to maximum effort testing. Two repetitions of each strength test were performed with a rest period of five seconds between each repetition and thirty seconds between each test. The swimmer was asked to gradually build up to a maximum force and maintain the effort, then relax when instructed after a total of five seconds. Verbal encouragement was provided during testing to produce a maximum effort matched by the tester (*make* test).

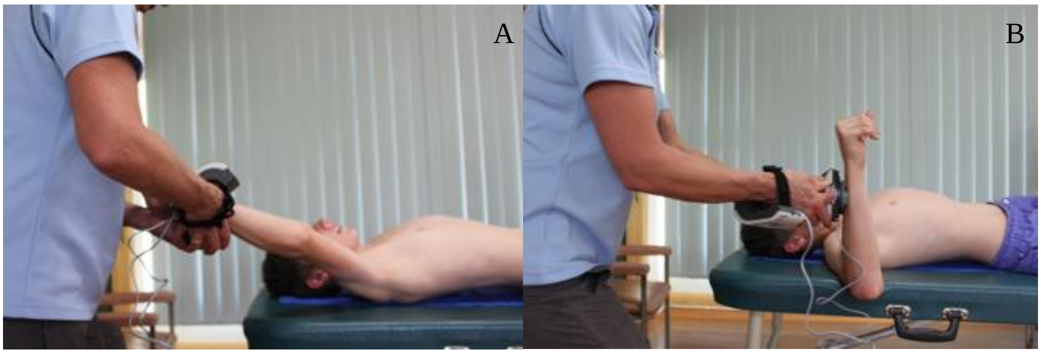

Figure 4.1 *Shoulder strength tests performed on swimmers*
A. *Flexion strength test.* ***B.*** *External rotation strength test.*

The maximum value (Newtons) recorded from the two repetitions of each test was normalised to BW (strength /BW x 100) to determine a relative strength measure expressed as a percentage of BW. This allowed for valid comparison of strength values between swimmers of different sizes. Ratios for IR:ER and FL:EX were calculated for each swimmer from the relative strength values (for example: IR/ER) and were reported as a single number. Shapiro-Wilk tests for normality were performed for all variables. Differences between groups (based on gender, history of pain, arm dominance, FL, EX and IR, ER relative strength) for all normally distributed data were explored using independent and dependent (arm dominance) *t* tests (α=0.05) and Levene's test for equality of variances. Mann-Whitney and Wilcoxon signed rank tests were applied to the non-parametric data groups. Spearman's rank order correlation was used to investigate correlation of training hours with strength data, age and best time. All data analyses were performed with SPSS (Version 20, IBM Corp, Armonk, NY, USA).

4.4 Results

Eighty-six swimmers with a mean age of 15.5 yrs (range 14-20 yrs) participated in this study and included 37 males (mean weight 69.3 ±10.5kg) and 48 females (mean weight 61.5 ±7.4kg) who trained for an average of 11.7 hours (range 6-30 hours) per week.

One swimmer was unable to complete the strength testing due to shoulder pain resulting in 85 swimmers tested. Twenty-seven (32%) swimmers (11 males and 16 females) reported a previous history of shoulder pain either unilaterally or bilaterally.

Relative isometric shoulder strength measures and ratio values (**Table 4.1)** were normally distributed and significantly different between the male and female groups ($p<0.002$). There was no significant difference in relative strength between dominant and non-dominant sides except for EX for males ($p<0.05$). Relative shoulder EX strength was significantly greater than FL strength ($p<0.001$) and IR strength was greater than ER strength ($p<0.001$) for both males and females.

The shoulder ratio strength data was not normally distributed when grouped for gender. There was no significant difference in the median FL:EX and IR:ER ratios between the female and male groups or between dominant and non-dominant sides (**Table 4.1**).

Relative isometric shoulder strength measures and ratio values for swimmers with and without a history of shoulder pain were normally distributed and are presented in **Table 4.2**. Swimmers with a history of shoulder pain did not demonstrate a significant difference in strength or strength ratios compared to those without pain. Training hours significantly correlated with age ($p<0.003$) for both sexes and the IR:ER ratio on the non-dominant side for females ($p<0.01$) but not for any relative strength measures.

Table 4.1 *Mean (± standard deviation) isometric shoulder strength relative to body weight (%) and median (range) shoulder strength ratios*

Test	Females		Males	
	Dominant	**Non-dominant**	**Dominant**	**Non-dominant**
Flexion	10.9 (±1.9) [ab]	10.6 (±1.9) [ab]	13.2 (±2.2) [ab]	12.9 (±2.0) [ab]
Extension	12.0 (±3.4) [ab]	11.8 (±3.6) [ab]	15.4 (±4.6) [abd]	14.4 (±3.8) [abd]
Internal Rotation	20.3 (±4.4) [ac]	20.1 (±4.8) [ac]	25.2 (±5.2) [ac]	25.2 (±4.6) [ac]
External Rotation	18.5 (±3.4) [ac]	18.1 (±3.4) [ac]	21.5 (±4.2) [ac]	21.2 (±4.5) [ac]
FL:EX Ratio	0.93 (0.59-1.64)	0.93 (0.59-1.59)	0.86 (0.58-1.64)	0.87 (0.65-2.00)
IR:ER Ratio	1.09 (0.59-1.60)	1.09 (0.68-1.43)	1.15 (0.91-1.50)	1.16 (0.97-1.70)

Abbreviations: FL, flexion; EX, extension; IR, internal rotation; ER, external rotation.

Significant difference between: [a] males and females for each test p<0.002; [b] flexion and extension strength p<0.001; [c] internal and external rotation strength p<0.001; [d] dominant and non-dominant sides p<0.05.

Table 4.2 *Mean (standard deviation) isometric shoulder strength relative to body weight (%) and mean (standard deviation) strength ratios for swimmers with and without a history of shoulder pain.*

	History of pain	No history of pain	p value
Flexion	12.6 (±1.7)	11.8 (±2.3)	0.35
Extension	14.1 (±3.9)	13.6 (±4.1)	0.83
Internal Rotation	23.7 (±3.7)	22.5 (±5.2)	0.91
External Rotation	20.3 (±2.9)	19.8 (±4.3)	0.81
FL:EX	0.97 (±0.26)	0.94 (±0.25)	0.33
IR:ER	1.15 (±0.17)	1.14 (±0.18)	0.87

Abbreviations: ER, external rotation; EX, extension; FL, flexion; IR, internal rotation.

4.5 Discussion

This is the first study to establish FL and EX shoulder strength measures in a swimming cohort. Relative shoulder EX strength was significantly greater than FL strength bilaterally in both male and female swimmers. This result is consistent with the bilateral contribution of powerful shoulder EX to assist pulling the body over the arm through the water in the freestyle stroke action which is used in the majority of swim training for all swimmers.[51]

As would be expected, male swimmers were significantly stronger than females[38] in relative FL and EX shoulder strength. There were no significant differences in FL strength between dominant and non-dominant sides in male or female swimmers, with relative FL strength in males approximately 13% and in females slightly greater than 10.5% bilaterally. In female swimmers, relative shoulder EX strength was approximately 12% with no significant differences bilaterally; however, in males there was a small but significant difference in relative EX strength, with the dominant side stronger (15.4%) than the non-dominant side (14.4%).

Relative shoulder FL strength using hand-held dynamometry has previously been examined in an elevated shoulder position in a large study of healthy young adults (n=619; mean age=19 yrs).[91] Although the tests for this young active group were performed in the prone position, results are comparable to the current study with similar relative shoulder FL strength values reported (males: 11-12%; females: 10%).[91] It would appear that swimmers and the normal population do not differ in FL strength, perhaps a consequence of the shoulder flexor group not directly generating power in the swimming stroke. Values for EX strength measured in elevation have not been reported previously for the normal population or swimmers.

Despite differences in relative shoulder strength, the FL:EX strength ratios for males and females were similar (**Table 4.1**) and suggest a common muscle balance which biases EX strength over FL strength ($p<0.001$). Strength ratios have been considered important in monitoring the muscle balance around joints.[37, 41] This novel FL:EX ratio performed in elevation may be a useful measure to assist in monitoring shoulder strength balance in the swimmer due to its functional relevance to the sport.

Males were significantly stronger than female swimmers in relative shoulder IR (males 25%; females 20%) and ER strength (males 21%; females 18%), which is in agreement with previous shoulder rotation strength measures reported for the general population[91, 120] and swimmers.[20] Similar to the FL and EX strength ratio previously discussed, IR:ER strength ratios were not significantly different for males and females (**Table 4.1**), again suggesting a common muscle balance for both groups of swimmers.

No differences were found between the dominant and non-dominant sides for IR and ER strength tests for male or female swimmers, consistent with the bilateral nature of the sport. Results of the current study are comparable to previous reports of similarities between limbs for shoulder IR and ER strength in older swimmers.[19, 37, 38] In contrast, Ramsi et al.[20] found IR and ER strength differences between the dominant and non-dominant sides in young swimmers (n=27; mean age=16 yrs), more reflective of a non-swimming population.[120, 121] In the clinic comparisons are often made between the pain-free and painful shoulder. For athletes involved in unilateral sports this comparison may not be valid (due to the increased strength of the dominant side)[66, 122] hence, unilateral strength ratios are more informative. Given that IR and ER strength values did not differ bilaterally for swimmers, relative strength values for rotation tests (and indeed FL strength tests) provide a valid, and perhaps more sensitive, comparison than strength ratio measures. However, due to the side-to-side differences in EX relative strength found in pain-free male swimmers in this study, FL:EX strength ratios provide a reliable comparison between limbs for this strength measure.

Comparison of IR and ER strength results with other studies on young swimmers is difficult because strength was not normalised to BW[20] and different protocols employing isokinetic dynamometry in sitting were utilised.[87] A study on a normal, young population using a similar protocol to the current study (in supine but 45° shoulder abduction), reported comparable IR and ER relative strength values.[91] Although in contrast to the current study, side-to-side differences were found for IR strength, with the dominant side stronger than the non-dominant side. The swimming cohort such as the one in the current study perform repetitive arm actions bilaterally consistently in swim training and consequently have fewer side to side shoulder strength differences compared to the normal population.[91, 120]

The greater IR strength compared to ER strength reflected by the ratio values for males and females (**Table 4.1**) in this study appears to be a consistent finding in previous studies reporting IR:ER shoulder strength ratios in swimmers.[18, 20, 36] Strength test results using a HHD in a similar age group of swimmers (mean age of 16 yrs) revealed IR:ER strength ratios comparable to the current study, of 1.12 for males and 1.10 for females,[20] however; higher IR:ER strength ratios of up to 1.37 were calculated on male swimmers (mean age of 15 yrs) performing isokinetic strength tests in sitting.[87]

There was no difference in the relative shoulder strength of FL, EX, ER or IR between swimmers who reported a previous history of shoulder pain and those who did not (**Table 4.2**). In addition, FL:EX and IR:ER strength ratios were the same for swimmers with and without a history of pain (**Table 4.2)**. This finding of no relationship between relative strength or strength ratio measures and previous shoulder pain concurs with an earlier investigation on swimmers which found that IR:ER shoulder strength ratios did not differ between groups with and without a history of shoulder pain.[18] Although the pain free inclusion criteria was clearly explained, this was a reflective question relying on memory and as many swimmers believe some pain in their shoulders during swimming is normal,[70] it is possible that the history of pain was under reported in the current study. In addition, strength values are limited to the ranges tested and cannot be generalised to throughout the freestyle stroke. The relationship between shoulder pain and shoulder strength parameters in young swimmers who are currently experiencing shoulder pain, which prevents them from training, and competing remains to be established.

4.6 Conclusion

The FL, EX, IR and ER strength tests performed have contributed clinically useful normative data providing an important reference to benefit the assessment and treatment of swimmers. The described protocol using a HHD, a cost effective and portable tool, can be performed in the clinic or poolside by a single clinician. While there were consistent shoulder strength differences between males and females, shoulder strength ratios were the same. Shoulder strength was similar on both the dominant and non-dominant sides, except for EX in males. All shoulder strength parameters were independent of a history of shoulder pain. This normative data may aid future investigations in the relationship between shoulder strength and shoulder pain in swimmers.

4.7 Practical Implications

- Normal shoulder strength (expressed as a percentage of BW) and strength ratio values for the young swimmer offer clinicians a point of comparison when assessing shoulder strength provided the same test protocol is used.
- When strength testing young swimmers without shoulder pain the following could be expected: males are stronger than females but FL:EX and IR:ER strength ratios do not differ between sexes; generally, shoulder strength is equal bilaterally and both swimmers with and without a history of shoulder pain have similar relative shoulder strength and strength ratio measures.
- The novel FL and EX tests which can be performed in the clinic or poolside may enhance a functional musculoskeletal screening and shoulder strength assessment of the swimmer.

Acknowledgments

The authors thank the swimmers and coaches for their participation in this study and acknowledge Justin Ockerby and Dr Helen Walker for their assistance in data collection. Thank you to the University of Tasmania for providing equipment and financial assistance for this project.

Chapter 5. Scapular upward rotation in swimmers is symmetrical in swimmers without current shoulder pain

An original version of this chapter has been published in the journal: Physical Therapy in Sport and appears in the literature as:

McLaine, SJ., Ginn, KA., Fell, JW. and Bird, M-L. Scapular upward rotation in swimmers is symmetrical. *Physical Therapy in Sport.* 2017; 29(9-13).

Journal Impact Factor: 1.919

Minor formatting changes for the purpose of inclusion into this thesis have been made to the original accepted version of this manuscript.

Rationale: Scapular UR position has been postulated as a factor that may contribute to shoulder pain in swimmers, however, results are conflicting and sample sizes small. Scapular UR position in a large cohort of pain-free swimmers has not been assessed and may help to inform clinicians of what is a normal expectation for scapular position when measured in elevated shoulder positions, similar to those typically reached in swimming. Knowledge of normal scapular UR parameters for a young swimming population will benefit clinicians assessing swimmers' shoulders.

5.1 Abstract

Objectives: A history of shoulder pain is common in swimmers and may influence scapular position, possibly increasing the risk of shoulder pain recurring. The aim of this study was to establish and compare bilateral static measures of scapular upward rotation in swimmers (14-20 yrs), some with a history of shoulder pain but all currently pain free, in two different elevated positions of shoulder abduction. *Design:* Cross-sectional, observational study. *Participants:* Eighty-five swimmers without current shoulder pain *Methods:* Scapular upward rotation position was measured on both shoulders using a digital inclinometer in 90° and 140° shoulder abduction. Descriptive statistics were calculated for degrees of scapular upward rotation in both shoulder positions. Differences between shoulders (dominant, non-dominant, history and no history of pain) were explored using one-way ANOVA and paired *t* tests. *Results:* A large range of values for scapular upward rotation was found at both positions of shoulder abduction but there were no significant differences between the shoulders: with and without a history of shoulder pain for the dominant and non-dominant sides. *Conclusions:* A history of shoulder pain and arm dominance did not influence scapular upward rotation position when measured in shoulder abduction in swimmers without current shoulder pain.

Keywords: shoulder; scapula; shoulder pain; rotation; swimming; scapular kinematics.

5.2 Introduction

Shoulder pain is common in young swimmers with prevalence proportions as high as 91% for swimmers who have experienced shoulder pain[1] and incidence rates increasing by more than tenfold for swimmers with a previous history of shoulder pain[51, 123]. Clinicians commonly assess and treat swimmers' shoulders using objective measures to assist clinical decision making. Given that changes in scapular position, in particular UR, have been shown to be associated with shoulder pain and fatigue in swimmers[13, 111, 124], measurement of scapular position may be included in the clinical assessment.

Full range of shoulder elevation is essential for swimmers and must be accompanied by adequate scapular rotation around three axes to posteriorly tilt, externally and upwardly rotate the scapula to ensure dynamic movement coupled between the arm and shoulder[23, 105]. Approximation of the glenoid to the humeral head, optimisation of the length-tension relationship of the rotator cuff muscles and elevation of the acromion will occur as a result of effective scapular positioning in arm elevation. Scapular UR range of movement increases with shoulder abduction[23, 46] and is the only scapular movement that has been reported as a reliable measure which can be performed in the clinic using an inclinometer[14]. When measured in elevated positions of shoulder abduction the assessment of scapular UR is functionally relevant, particularly for athletes performing repetitious overhead movement such as the swimmer who may elevate the arm over 2000 times in a swim session[125].

Movement dysfunction can be identified only if normal function has been defined. Clinicians assessing the upper limb may refer to normative data and compare the symptomatic side to the contralateral side in order to guide treatment and determine the effectiveness of an intervention. However, there is a lack of data with respect to what is a normal scapular UR position for the shoulder and whether side to side symmetry can be expected for swimmers without shoulder pain. Hence, currently it is difficult to accurately identify abnormal scapular UR in the assessment of the swimmer's painful shoulder. Therefore, investigating scapular UR in a large group of swimmers without current shoulder pain will further inform clinical decisions for this sporting population.

The aim of this study was to investigate and compare the degree of scapular UR measured at 90° and 140° of shoulder abduction in pain-free swimmers with and without a previous history of shoulder pain; and to identify differences between the dominant and non-dominant arms within swimmers.

5.3 Materials and Methods

5.3.1 Participants

Club swimmers aged 14-20 yrs without current or recent shoulder pain (within the previous two months) who trained at least six hours per week participated in this study. Recruitment was initiated by a letter of invitation to participate, which was distributed to coaches of swimming clubs, locally situated for convenience. Swimmers who were pain-free were identified by coaches and invited to participate. An explanation of the study was provided to coaches, swimmers and their parents by the primary investigator. Exclusion criteria included: a history of shoulder dislocation, neck or shoulder surgery, and recent shoulder pain within the past two months (defined as causing the swimmer to miss or significantly modify two or more training sessions). Potential participants were excluded if shoulder pain was reported during the testing procedure.

Swimmers completed a questionnaire on previous shoulder pain, training history and hand dominance. Prior to testing, swimmers (or parents/guardians if the swimmer was under 18 yrs) completed an institutional informed consent form and the institution's review board approved the study.

5.3.2 Testing instrument

An ACUMAR™ digital inclinometer (Model ACU 001) Lafayette Instrument Company (Lafayette, IN 47904) was used to measure the scapular UR position statically by aligning the base along the spine of the scapula (**Figure 5.1**). The inclinometer has been shown to have good to excellent intra-rater reliability in the measurement of scapular UR with a test-retest interval of 30 minutes[14]. A priori reliability was established by the primary investigator in a sample of convenience (university students and staff without shoulder pain; n=15, mean age=24 yrs) measured on two occasions, one week apart. The intraclass correlation coefficient ($ICC_{3,1}$) (2-way mixed with absolute agreement) and standard error of measurement (SEM) values for scapular UR at 90° of shoulder abduction on the dominant and non-dominant side were 0.76; 2.4° and 0.86; 1.2° respectively; and at 140° shoulder abduction, 0.83; 1.3°and 0.62; 2.7° respectively (**Appendix D**).

5.2.3 Scapular angle measurement

Swimmers reported poolside for a single testing session before commencing normal swim training. After performing full range shoulder abduction five times, each swimmer moved the arms to reach 90° shoulder abduction in the frontal plane with the elbows extended and shoulders in ER with palms facing anteriorly. Bilateral static measurements of scapular UR angle were recorded at 90° and 140° shoulder abduction, with swimmers resting the arms by their side for 20 seconds in between measurements. Each measurement was performed in no more than ten seconds to avoid fatigue. A goniometer, a reliable clinical tool[126], was used by the second researcher (an experienced Exercise Physiologist) to ensure that the correct arm abduction angle was reached and maintained while the primary investigator (a Sports Physiotherapist with 12 yrs of experience in using an inclinometer) placed the inclinometer along the scapular spine and measured the scapular UR angle. Both researchers were blinded to arm dominance and previous pain history. Swimmers were instructed to keep the arm still and the trunk upright during all measurements.

Figure 5.1 *Measurement of scapular upward rotation at 90° shoulder abduction (goniometer removed for the photo)*

5.2.4 Statistical analysis

Shapiro-Wilk tests for normality were performed for all variables (age, training hours, best 100m freestyle time and scapular UR) before calculating descriptive statistics. Levene's tests for equality of variances and Mann Whitney U tests were used for non-parametric data analysis. One-way ANOVA was used to compare scapular UR values between four groups of shoulders: dominant shoulders with and without a previous history of pain; and non-dominant shoulders with and without a history of pain. Confidence intervals were calculated for the differences between arms within the groups who reported both a history of pain and no pain. To determine any side-to-side differences within swimmers paired *t*-tests were used. Comparison of side-to-side scapular UR position was investigated further within the subgroup of swimmers who had a history of unilateral shoulder pain using paired *t*-tests. Alpha was set at 0.05 and all data analyses were performed with SPSS (Version 20, IBM Corp, Armonk, NY, USA).

5.4 Results

Eighty-nine swimmers volunteered for this study. Three were excluded due to recent shoulder pain and one was excluded due to pain reported during testing. Demographic data for 85 swimmers who did not have shoulder pain at the time of testing are presented in **Table 5.1**. Twenty-seven (32%) swimmers reported a previous history of shoulder pain on either the dominant side (n=8 or 30%), the non-dominant side (n=9 or 33%), or bilaterally (n=10 or 37%). A total of 37 shoulders had a reported history of pain (18 dominant and 19 non-dominant) and 133 shoulders had no history of shoulder pain (66 dominant and 67 non-dominant). Training hours per week and age were not normally distributed but best time data showed a normal distribution. There were no significant differences in the median hours of swim training per week or mean best time for 100m of freestyle swimming between swimmers who reported a history of shoulder pain and those who did not, but the latter group was two years younger (p=0.02).

Table 5.1 *Demographics of swimmers (n=85) with and without a history of shoulder pain*.

	History of pain (n=27)	No history of pain (n=58)
Males (n)	11	26
Females (n)	16	32
Age yrs; median (range)	*17.0 (14-20)	*15.0 (14-20)
Hours trained per week; median (range)	12.0 (6-21)	10.5 (6-36)
100m freestyle best time, sec; mean (SD)	60.6 (6.9)	62.7 (6.0)

Abbreviations: m, metres; n, number; sec, seconds; SD, standard deviation; yrs, years.

* significant difference (p=0.02)

All scapular UR position data were normally distributed. The mean, standard deviation (SD) and range for scapular UR angle for all shoulders (n=170) at 90° and 140° shoulder abduction was 30° (±8.7, 10-50°) and 52° (±7.8, 30-70°) respectively. Mean, SD and range values for scapular UR for the four groups of shoulders (dominant shoulders with a history of pain, dominant without a history of pain and non-dominant shoulders with and without a history of pain) are presented in **Table 5.2.** One-way ANOVA analysis of the 170 shoulders demonstrated no differences in mean scapular UR position between the four groups at either 90° shoulder abduction (p=0.52) or 140°

(p=0.43). A large variability (range) in values was found for all groups at both shoulder abduction angles.

Table 5.2 *Mean (±SD), range of scapular upward rotation (degrees) for dominant and non-dominant arms at 90° and 140° of shoulder abduction for shoulders with and without a history of pain.*

Shoulder abduction position	**Shoulders with a history of pain**		**Shoulders with no history of pain**	
	D (n=18) Mean (±SD) range	**ND (n=19)**	**D (n=66) Mean (±SD) range**	**ND (n=67)**
90°	30.9 (±9.5) 11-47	27.4 (±8.6) 10-48	30.6 (±8.6) 11-48	30.0 (±8.5) 10-50
140°	54.6 (±6.4) 42-68	53.1 (±7.8) 42-70	51.5 (±8.1) 30-68	51.6 (±7.9) 31-70

Abbreviations: D, dominant; N, non-dominant; n, number; SD, standard deviation.

Paired *t*-tests showed no differences in scapular UR position between the dominant and non-dominant arms within swimmers without a previous history of pain at 90° shoulder abduction (31°±8.6° and 30°±9.0° respectively, *p*=0.16) and at 140° (52°±8.0° and 51°±7.9° respectively, p=0.08). No differences were found within swimmers with a previous history of pain (unilateral and bilateral included) at 90° shoulder abduction (31°±9.0° and 29°±8.2° respectively, p=0.07) and at 140° (52°±7.5° and 51°±8.9° respectively, p=0.09) The absolute mean difference (95% CI) in scapula upward rotation between dominant and non-dominant sides in swimmers with previous pain was 4.75° (3.57-5.92) at 90° shoulder abduction and 3.5° (2.47-4.53) at 140 ° and in swimmers without previous pain it was 4.72° (4.01-5.43) at 90° shoulder abduction and 3.49° (2.82-4.16) at 140°.

Further analysis of the subgroup of swimmers (n=17) who reported a unilateral history of shoulder pain demonstrated similar mean (SD) scapular UR values for both the side that had a history of pain and the side without, at 90° shoulder abduction (30°±7.4° and 32°±6.1° respectively, p=0.11) and at 140° (52°±8.3 and 52°±7.8°, p=0.64).

5.5 Discussion

Angles of scapular UR measured in elevated shoulder abduction positions have been established for a large cohort of swimmers without current shoulder pain using clinically accessible tools. There were no differences in scapular UR angles between dominant and non-dominant shoulders with and without a history of pain at 90° and 140° shoulder abduction. Additionally, similar values for scapular UR for the subgroup of swimmers who reported a history of unilateral shoulder pain indicate that a history of shoulder pain does not affect scapular UR position in swimmers. Notably, across this pain free swimming cohort, a wide *range* of values was recorded for scapular UR positions measured at both shoulder abduction angles (90°: mean 30°; range 10-50°;140°: mean 52°; range 30-70°), which suggests that in a swimming population a highly variable degree of upward rotation of the scapula during shoulder abduction is a normal finding.

Previous research investigating positions of scapular UR in shoulder abduction using an inclinometer have reported mean values similar to the current study also with large group variation. In both a swimming cohort[15] and a population who were not specifically swimmers[14], mean values and ranges for scapular UR angles measured at 90° shoulder abduction of 34° (range 26-41°) and 28° (range 0-56°) respectively were reported. Despite the fact that these studies included subjects with shoulder pain, similar mean scapular UR angles with equally large variability to the current study (mean 30°; range 10-50°) were found. For swimming populations, mean scapular UR angles of 27° (measured at 90° shoulder abduction) in pain-free swimmers[26] and 35° in swimmers with shoulder pain[13] have also been reported (without comment on the variability). As the large cohort of swimmers in this current study were pain free at the time of testing it appears that when measured in shoulder abduction, mean scapular UR angles are typically similar in both swimmers and the general population regardless of shoulder pain status. Additionally, a high variability in scapular UR angles at 90° abduction appears to be a normal finding and not uniquely associated with shoulder pain.

Arm dominance did not influence scapular UR angles at either 90° or 140° of shoulder abduction for swimmers without current shoulder pain. Although scapular UR angle between swimmers was variable in this large group, paired *t*-tests confirmed symmetry *within* individuals which was unaffected by the presence of a history of shoulder pain. This is consistent with a previous report which found symmetrical scapular UR in ten pain-free swimmers when measured at 90° shoulder abduction[26] and might be expected in a bilateral sport like swimming. These results would suggest that a side-to-side difference in scapular UR measured in swimming athletes with unilateral shoulder pain is potentially a significant clinical finding. In contrast, greater angles of scapular UR in elevated ranges of abduction have been reported on the dominant side for the unilateral overhead athlete, such as a thrower or tennis player[127, 128]. Normative values for scapular UR are less informative with such a high degree of variability; however, the clinician may rely on the contralateral side for comparison when assessing swimmers' scapular UR position in shoulder abduction.

Given the current study's results of symmetrical scapular UR angle in abduction within pain-free swimmers in the presence of a large population variability, side-to-side differences in symptomatic swimmers are potentially more sensitive in determining any relationship between scapular UR angle and shoulder pain. Comparison of mean values for scapular UR angle between different groups is problematic and may explain the conflicting results from previous research. Both increased[52] and decreased scapular UR angles[107] have been reported in general population cohorts with shoulder pain compared to pain-free populations. However, a within group bilateral comparison found no differences in scapular UR position in the presence of pain[105]. Su[13] compared a pain free swimming group to swimmers who experienced pain during and after a swim session but were pain free before the session (mean age of both groups=24 yrs). Scapular UR position was the same for both groups before the swim but scapular UR was less for the pain group when measured after the swim session. This was supported by side-to-side differences within the shoulder pain group of swimmers, finding less scapular UR on the symptomatic side after a swim session but not before[13]. These results concur with the current study which investigated a younger swimming cohort (mean age=15 yrs), suggesting that in the absence of pain symmetrical scapular UR can be expected in swimmers. It is feasible that shoulder pain may influence scapular UR position, therefore comparison of scapular UR position *within* swimmers who have shoulder pain is a more clinically relevant measure in light of the current finding of bilateral scapular UR symmetry in pain-free swimmers. The results from Su[13] suggest that changes in scapular UR are the result of pain, not the cause, but further research measuring scapular UR in the presence of pain and when pain has resolved would help to confirm any cause and effect relationship.

Thirty-two percent (n=27) of swimmers in the current study reported a past history of shoulder pain. This low prevalence proportion compared to those reported in the literature[1] is to be expected as the population in the current study excluded swimmers with recent or current pain. A history of shoulder pain did not influence scapular UR position during abduction. There were no differences in mean UR angle at 90° and 140° shoulder abduction (p=0.52 and 0.43 respectively) and similar UR angle ranges for swimmers with a history of shoulder pain compared to those without a history measured at 90° shoulder abduction (10-48° and 10-50° respectively) and 140° (42-70° and 30-70° respectively) were recorded. The current finding that previous shoulder pain did not influence scapular UR position was further supported when side-to-side symmetry was compared within the subgroup of swimmers (n=17) who reported unilateral shoulder pain. No differences in scapular UR position were found bilaterally at 90° (p=0.11) or 140° shoulder abduction: (p=0.64).

Currently, scapular UR is the only scapular movement that can be measured in the clinic using an inclinometer with documented reliability[14, 16, 129]. A priori reliability tests for scapular UR measures for the current study demonstrated excellent reliability for the majority of measures (ICC 0.81-0.96, except on the non-dominant arm at 140° abduction; ICC 0.62) which is similar to that achieved in previous studies[14, 16]. Furthermore, the SEM for the a priori reliability established for the current study was similar or less (1.2-2.7°) than values previously reported (2.0-2.6° and 3.8-5.2°) for comparable positions of shoulder abduction[14, 16]. Therefore, the large variability in scapular UR measures for this swimming cohort which is comparative to previous studies[14, 15] is a likely representation of this population.

5.6 Conclusion

The results indicate that variability of scapular UR position measured in shoulder abduction is normal in a large population of pain-free swimmers. However, scapular UR position is symmetrical from side-to-side within swimmers who do not have current shoulder pain regardless of a previous history of shoulder pain. Therefore, although mean values for scapular UR angle in shoulder abduction are of limited value, even for a homogenous sporting population like swimmers, side-to-side differences in scapular UR position in individual swimmers represent deviation from normal mechanics in this bilateral upper limb sport.

5.7 Highlights

- Scapular UR angles are variable in swimmers when measured in shoulder elevation.
- Scapular UR position is symmetrical in swimmers without current shoulder pain.
- Shoulder pain history does not influence scapular UR position in shoulder abduction.

Chapter 6. Shoulder extension strength: a potential risk factor for shoulder pain in young swimmers?

An original version of this chapter has recently been accepted (November 2018) for publication in the Journal of Sports Medicine and Science as an original research investigation:

McLaine SJ, Bird M-L, Ginn KA, Hartley T and Fell JW. Shoulder extension strength: a potential risk factor for shoulder pain in young swimmers? *Journal of Science and Medicine in Sport* (Accepted November 2018)

Journal Impact Factor: 3.929

Minor formatting changes only have been made to the original version of the manuscript.

Rationale

It has been well documented that shoulder pain is a significant problem for young swimmers, yet there is a paucity of evidence related to modifiable factors that contribute to risk. Shoulder IR and ER strength has been investigated previously; however, questions remain around the relationship of strength to the development of shoulder pain due to a lack of prospective studies with larger sample sizes. This research aimed to investigate any associative and predictive value in shoulder strength and the development of shoulder pain in young swimmers.

6.1 Abstract

Objectives: To determine the relationship and predictive value of isometric shoulder strength in the development of shoulder pain in young swimmers. ***Design:*** Prospective, cohort study. ***Methods:*** Shoulder flexion, extension, external and internal rotation strength tests were performed in elevation on 85 swimmers (14-20 yrs; 48 females) without current shoulder pain using a hand-held dynamometer. Following testing, swimmers were emailed questionnaires to determine if significant shoulder pain developed within 24 months subsequent to testing. The differences between shoulders that did and did not develop pain and the predictive ability of shoulder strength and strength ratios were investigated using Mann Whitney U tests and receiver operating characteristic curves. *Results*: Thirty-seven swimmers (47%) returned questionnaires and 18 reported shoulder pain. A comparison of individual shoulders (27 with pain reported and 47 without) determined that shoulder extension strength was lower and flexion:extension strength ratio was higher for male swimmers (n=36 shoulders) who reported shoulder pain compared to those who did not (p=0.04). The predictive value of extension strength was fair (0.72; p=0.03) for males with a cut-off value for extension strength calculated at 13.5% body mass. There were no differences between the two groups in shoulder rotation strength, age, training hours or previous pain history. ***Conclusions:*** Shoulder extension strength, a functional test for swimmers, was associated with and predictive of the development of shoulder pain in male swimmers. Low shoulder extension strength may be a risk factor for the development of shoulder pain in swimmers, proposing a direction for injury prevention and future investigation.

Keywords: swimming, muscle strength, isometric contraction, shoulder joint, hand-held dynamometer.

6.2 Introduction

The shoulder is the most commonly reported region of pain in swimmers, causing an impact on training, competition and swimming goals for many young swimmers.[1, 28, 130] In all cohorts, shoulder pain prevalence in swimmers is high, increasing with time in the sport and may range from 40-91% depending on the age group and definition.[1, 28, 30] Many modifiable risk factors have been investigated in the literature and include range of shoulder rotation movement, shoulder muscle strength, shoulder muscle imbalance, flexibility, scapular kinematics, core stability, use of equipment, training load, swimming technique, dry land exercise and breathing side.[4, 33, 36, 51] Despite the investigation of numerous factors, many, including shoulder strength, have been evaluated to have a low level of certainty of predisposing a swimmer to shoulder pain, with no risk factor identified as having a high level of certainty.[4]

Injury prevention strategies are difficult to justify and may be misdirected when evidence regarding risk factors, such as shoulder strength, remains unclear. In some studies swimmers with shoulder pain have demonstrated reduced shoulder IR[36] and reduced shoulder ER strength compared to those without pain.[5] In contrast, no differences between swimmers with and without shoulder pain have been reported for shoulder IR or ER strength[37] and shoulder strength ratios (IR:ER).[18] The evidence is contradictory and has focussed on the association between variables rather than prediction analyses, which limits comment on risk.[72] Furthermore, the above-mentioned studies that examined the relationship between shoulder strength and pain reported shoulder strength values measured in the presence of pain. Therefore, it is not clear if any differences in strength are a consequence or a cause of shoulder pain, tissue damage, or indeed a result of different pain tolerance levels.[45] Maximal voluntary contraction values, for both static and dynamic muscle contractions, are reduced in the presence of pain,[46, 131] in particular, the painful shoulder has demonstrated delayed recruitment[24] and a change in motor strategy due to pain inhibition.[85] Hence, when strength is tested in the presence of shoulder pain, which may or may not be associated with tissue damage, swimmers' true capacity to generate force (strength) may be underestimated, subsequently misrepresenting a potential causal link between shoulder strength and the development of pain.

Knowledge of shoulder strength measurements performed without pain in positions functional to swimming could help clarify any relationship between shoulder strength and the development of shoulder pain. Shoulder IR and ER strength and their ratios have commonly been reported in swimmers, with changes in these values suggested as risk factors for shoulder pain; however, as outcomes are varied, there is no clear direction provided for an injury prevention intervention.[18, 36, 132] In contrast, shoulder FL and EX strength values have rarely been reported[133] and warrant further investigation, given the high propulsive EX forces generated by the swimmer in shoulder elevation and the ensuing challenge to the stabilising muscles of the shoulder.[40] Swimmers commonly report shoulder pain when force is generated in shoulder elevation, during early pull-through and the recovery position.[1, 5] In the first half of the pull-through phase in freestyle, force is generated in elevation as the shoulder moves into EX, adduction and IR and the body is pulled over the arm, initially with a long lever. During this phase activity has been demonstrated in: pectoralis major, latissimus dorsi, deltoid, the rotator cuff muscles and axioscapular muscles, to both move and stabilise the humerus and scapula.[24, 40, 79] Functional, shoulder strength tests performed in positions similar to those where pain is experienced may help identify swimmers with reduced capacity to develop force at these ranges.

Prospectively tracking the development of shoulder pain after a pain-free assessment of shoulder strength, will add to our understanding of any relationship between shoulder strength and pain, without pain inhibition confounding the strength values. The aim of this study was to examine the association and predictive ability of clinically useful isometric shoulder strength tests (FL, EX, ER and IR) and the development of shoulder pain in young swimmers.

6.3 Methods

Isometric shoulder strength values for IR, ER, FL and EX, were recorded bilaterally using a hand-held dynamometer for 85 young swimmers (48 females; 37 males) without current shoulder pain. Young swimmers were defined as adolescent and young adult swimmers (14-20 yrs) for the purposes of this study. Strength tests were performed in supine for shoulder FL and EX (in 140° abduction); and IR and ER (in 90° abduction) using a *make* test.[133] Shoulder strength ratios (IR:ER and FL:EX) were calculated from the relative shoulder strength values (reported as a percentage of BW). In addition to training frequency, personal and anthropometric data, any previous shoulder pain history was recorded at the strength testing session. For the purposes of this study, shoulder pain was defined as pain that prevented the swimmer from participating in normal training or competition for two or more sessions. All swimmers were tested prior to normal, scheduled swim training. The study was approved by the Health and Medical Human Research Ethics Committee for the University (H0012936).

An online questionnaire (**Appendix I**) to investigate if shoulder pain had been experienced since testing was created and pilot tested with an athlete and physiotherapist to assess the questions for clarity. The questionnaire consisted of seven questions to determine if shoulder pain had developed and if so: which shoulder was affected; an estimation of the swimming sessions modified or missed due to shoulder pain; training history; and if the swimmer had stopped swimming, reasons why this was the case. A prospective timeframe of 24 months was chosen in which to capture the onset of shoulder pain and data was collected in a two-stage process. All swimmers were emailed a link to the questionnaire between nine and eighteen months after the strength testing session. The link was resent approximately 24 months after testing to non-responders and to swimmers who had reported that they had not experienced shoulder pain subsequent to strength testing in the initial questionnaire. Participants received a maximum of two reminders requesting completion of each questionnaire.

Data were collected via LimeSurvey (Limesurvey GmbH./LimeSurvey: An Open Source survey tool, Hamburg, Germany. URL http://www.limesurvey.org) and managed by a technical assistant supervised by the investigators. The shoulders of participants who responded to the questionnaire were grouped for side of pain or no pain (dominant, non-dominant and bilateral) then matched for analysis with the earlier recorded shoulder strength data for comparison.

Shapiro-Wilk tests for normality were performed and all analyses included data from only the swimmers who responded to the questionnaire. Mean age and estimated training times were normally distributed and investigated using t-tests to determine differences between the groups that reported shoulder pain and those that did not. Mann Whitney U tests investigated differences in the non-parametric shoulder strength data for swimmers who did and did not report subsequent shoulder pain and were used to determine differences between swimmers with and without a history of shoulder pain prior to testing. Receiver operating characteristic (ROC) curves were generated to investigate the ability of shoulder muscle strength variables to predict shoulder pain. Analysis of ROC curves examines a test's ability to classify subjects into groups by plotting the true-positive rate (sensitivity) and false-positive rate (1- specificity) along vertical and horizontal axes respectively. [134] For this study, the area under the curve (AUC) was calculated to report prediction accuracy, where a value of 1.0 is considered perfect; 0.9-0.99 excellent; 0.8-0.89 good; 0.7-0.79 fair; 0.51-0.69 poor and 0.50 is considered to be of no predictive value.[134] Youden's index (a summary measure for the ROC curve to enable the selection of an optimal threshold value, helpful in the selection of a cut-off point) was calculated for significant findings to determine optimum cut off points for strength variables.[134] A sample size of 30 was required for an area under the ROC curve of 0.80, set at alpha 0.05, beta 0.20 and null hypothesis value 0.50. Data analyses were performed with SPSS (Version 23, IBM Corp, Armonk, NY, USA) and Medcalc Software (Version 17.9, Ostend, Belgium).

6.4 Results

Of the 85 swimmers initially strength tested, 78 were successfully sent the questionnaire via an email link. Thirty-seven swimmers (47%) returned completed questionnaires and eighteen (n=27 shoulders) of these swimmers reported the development of shoulder pain (nine reported bilateral pain) in the time subsequent to testing (**Figure 6.1**). The average time for follow up and response subsequent to strength testing was 18 months (range 9-24 months). Swimmers who reported the development of shoulder pain had a similar estimated weekly training time to those that did not report pain (mean [SD] 10.3 ±6.6 and 10.9 ±6.3 hours, respectively) and mean age (16.3 ±2.1 and 16.4 ±1.8 yrs, respectively). A previous history of shoulder pain was recorded prior to initial strength testing for eight swimmers who reported the development of shoulder pain and nine who reported no pain since strength testing. There was no relationship between a historical episode of shoulder pain (prior to strength testing) and the development of shoulder pain in this group of swimmers for any strength values ($p > 0.20$).

Table 6.1 *Median (range) isometric shoulder strength relative to body weight (%), flexion-to-extension strength ratio (FL:EX) and internal rotation-to-external rotation strength ratio (IR:ER) for male and female shoulders with and without pain*

Strength variable	Female shoulders			Male shoulders		
	Pain reported n=15	**No pain reported n=23**	**p**	**Pain reported n=12**	**No pain reported n=24**	**p**
FL	9.94 (7.80-14.32)	11.22 (5.99-13.90)	0.22	12.66 (10.40-17.05)	13.48 (9.89-17.18)	0.16
EX	10.10 (6.29-20.57)	12.31 (5.99-19.61)	0.10	**12.35 (7.06-28.06)**	**16.55 (9.51-21.30)**	**0.04**
IR	17.52 (14.03-26.21)	20.25 (11.58-29.80)	0.21	25.43 (19.16-30.34)	26.12 (15.60-33.93)	0.40
ER	17.86 (13.48-26.57)	18.80 (11.07-25.16)	0.31	19.24 (16.92-27.39)	22.65 (15.60-26.53)	0.30
FL:EX	0.97 (0.50-1.64)	0.93 (0.63-1.17)	0.36	**1.00 (0.59-1.64)**	**0.85 (0.68-1.51)**	**0.04**
IR:ER	1.06 (0.68-1.28)	1.07 (0.59-1.43)	0.48	1.23 (0.97-1.47)	1.18 (0.93-1.46)	0.50

Abbreviations: ER, external rotation; EX, extension; FL, flexion; IR, internal rotation.

From the follow up questionnaire, pain was reported in 27 shoulders (15 female; 12 male) with no pain reported in 47 shoulders (23 female; 24 male). A comparison of strength values for the shoulders with and without pain is presented in **Table 6.1.** For male swimmers, EX strength was lower in shoulders which had developed pain (median 12.35% BW; range 7.06-28.06; p=0.04) compared to those with no reported experience of shoulder pain (16.55% BW; 9.51-21.30; p=0.04) with no difference in FL strength between these groups (p=0.16). Consequently, for male swimmers the FL:EX strength ratio was higher for the shoulders with pain reported in the follow-up questionnaire, compared to those with no shoulder pain (median 1.00; range 0.59-1.64 and 0.85; 0.68-1.51 respectively; p=0.04). There was no difference between the groups of males in IR (p=0.40) or ER strength (p=0.30) or IR:ER strength ratio (p=0.50). For the female swimmers there were no significant differences in shoulder muscle strength values (FL, EX, ER, IR) or ratios (IR:ER and FL:EX) between the shoulders that developed pain and those that did not (p≥0.05).

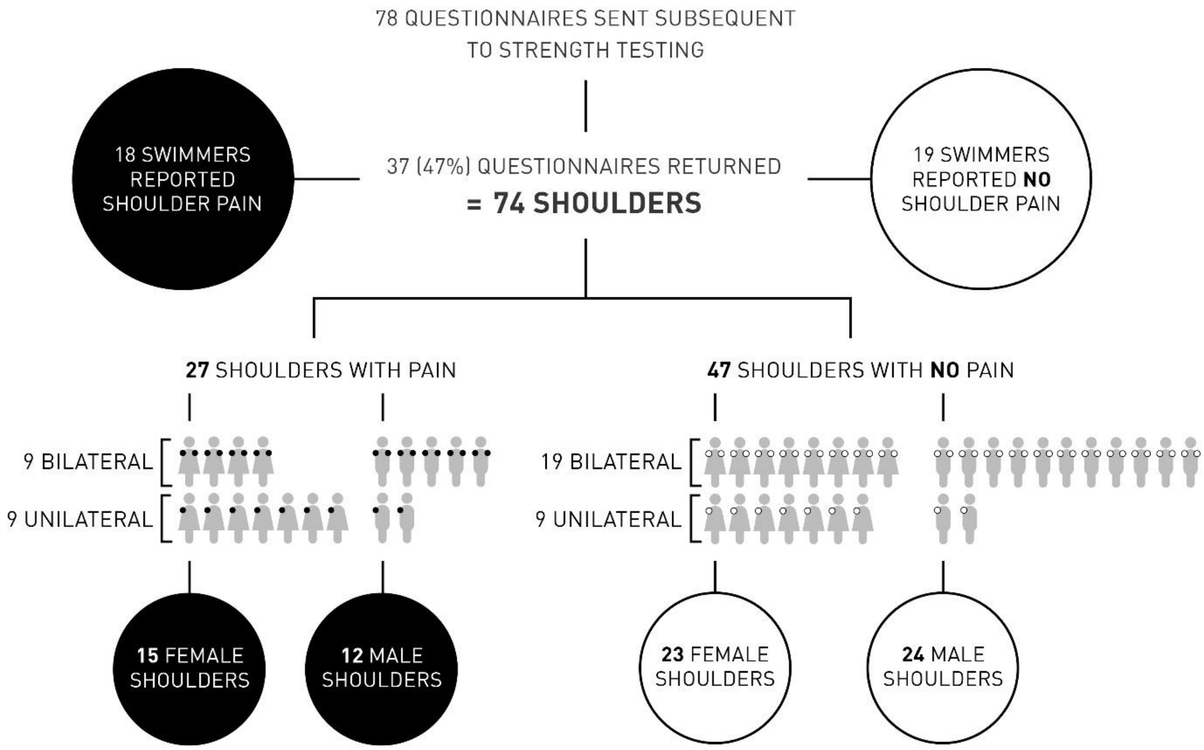

Figure 6.1 *Response to questionnaire: number of swimmers' shoulders (male and female) with reported pain or no pain subsequent to strength testing.*

The predictive value (determined by the AUC) of EX strength and FL:EX ratio was 0.72 and 0.71 (fair predictive value) respectively for male swimmers (**Table 6.2**). No other shoulder strength tests for males or females demonstrated predictive values greater than 0.70 ($p>0.12$). The optimal cut off value for shoulder EX strength, as a predictor for shoulder pain, for males was 13.5% BW, determined by the highest Youden's index (0.42). Male swimmers in this cohort with EX strength less than 13.5% BW had a fair chance of developing shoulder pain within the 24 month follow-up period.

Table 6.2 *Area under the ROC curve (Area), standard error (SE), asymptotic significance (p) and 95% confidence interval (CI) for male and female shoulder pain predictor variables: relative shoulder strength and strength ratios.*

Strength variable	Females				Males			
	Area	SE	p	CI	Area	SE	p	CI
FL	0.62	0.10	0.22	0.43-0.82	0.65	0.11	0.15	0.44-0.86
EX	0.66	0.10	0.12	0.49-0.81	**0.72[a]**	**0.09**	**0.03**	**0.54-0.86**
IR	0.62	0.09	0.20	0.44-0.81	0.59	0.10	0.38	0.39-0.79
ER	0.60	0.10	0.30	0.41-0.79	0.61	0.12	0.28	0.38-0.84
FL:EX	0.59	0.10	0.36	0.39-0.79	**0.71[a]**	**0.10**	**0.04**	**0.52-0.91**
IR:ER	0.43	0.10	0.49	0.23-0.63	0.43	0.10	0.49	0.23-0.63

Abbreviations: ER, external rotation; EX, extension; FL, flexion; IR, internal rotation.

[a]fair predictive value

6.5 Discussion

The results of this study suggest that shoulder EX strength and consequently FL:EX strength ratio have a significant relationship with the development of shoulder pain in young male swimmers. Further to this finding of association, predictive analyses indicate that shoulder EX strength, assessed in elevation when the swimmer is pain free, could be helpful in identifying young swimmers who may be at risk of developing shoulder pain, with low shoulder EX strength values demonstrating fair predictive value for the onset of shoulder pain in this group.

The male swimmers who developed shoulder pain were weaker in relative shoulder EX (12.35% BW) than those males who did not develop shoulder pain (16.55% BW; p=0.04), (**Table 6.2**). Furthermore, the AUC (0.72; p=0.03) suggested that shoulder EX strength in the male swimmer was a fair predictor for the development of subsequent shoulder pain, that is, on average shoulder pain could be predicted correctly 72% of the time. Male swimmers with shoulder EX strength less than 13.5% were more likely to develop shoulder pain than those with higher strength values as suggested by the Youden's index. While the AUC was significant and an indicator of the quality of the analysis,[134] the Youden's index (0.46) is not strong but is clinically useful in the provision of a suggested shoulder EX strength threshold and deserves further investigation with other cohorts. Given that findings of association and prediction were significant for low shoulder EX strength in males without shoulder pain and previously reported normative shoulder EX values for pain free male swimmers (n=85) were approximately 15% of BW,[133] strengthening exercises could be beneficial in the prevention of shoulder pain in young male swimmers with shoulder EX strength less than 13.5% BW.

In this cohort, male swimmers who developed shoulder pain recorded lower isometric shoulder EX strength than the group that did not develop shoulder pain, yet there were no differences between the groups in IR and ER strength. This is in contrast to previous studies that have reported differences in shoulder IR and ER rotation strength for swimmers with shoulder pain; however, the very presence of pain may have confounded results.[5, 36] Resisted shoulder EX in elevation, requires the coordinated recruitment and control of extensor torque producing muscles, rotator cuff muscles and axioscapular muscles.[24, 40, 79] While the rotator cuff muscles will be recruited in their stabiliser role to counterbalance potential destabilising forces produced by the shoulder extensor muscles (sternal head of pectoralis major, latissimus dorsi, teres major), the axioscapular muscles will be recruited to both rotate the scapula and stabilise it against potential destabilising forces produced by both shoulder extensor and rotator cuff muscles. The results from the male cohort in this study suggest that resisted shoulder EX, a functionally relevant strength test that requires rotator cuff muscles to function in their stabilisation role, is better able to identify swimmers at risk of developing shoulder pain than resisted rotation in which the rotator cuff muscles are functioning to produce rotation torque.[77]

For this cohort of adolescents and young adults diversity in developmental and growth stages involving change in upper limb lever length which may influence motor control and coordination around the shoulder is expected.[135, 136] Shoulder EX strength was not associated with the development of shoulder pain in female swimmers, in contrast to the findings for males. This is perhaps a result of differences in strength changes in male swimmers compared to females and different developmental stages.[137] A change in body dimension was not recorded in this study;

however, this is recommended for future investigations and could provide further understanding of risk factors for shoulder pain, which are no doubt multifaceted. Increases in the length of the upper limb will require not only increased shoulder EX strength for swimming but also increases in rotator cuff and axioscapular muscle strength which have to be well co-ordinated to counterbalance potential translation forces and maintain shoulder region stability.[77] We propose that if the ability to produce EX force via a long lever is reduced in the young swimmer, potentially, the capacity to achieve optimal shoulder joint stabilisation is reduced and the shoulder may be at risk of injury. The authors recommend monitoring young male swimmers with shoulder EX less than 13.5% BW as they may be at risk of developing shoulder pain. These swimmers may require training modifications and time to develop the strength, coordination and motor control required for swimming, particularly during rapid growth phases. Shoulder EX exercises in elevated positions may be helpful for this group.

The results of this study confirm that shoulder pain is common in a young swimming population. Approximately half of the 47% of swimmers who responded to the questionnaire reported the onset of shoulder pain within the two years subsequent to performing the strength tests when they were pain-free. Our results concur with other investigations that have reported high rates of shoulder pain in swimmers ranging from approximately 50%[30] up to 91%,[1, 5] reinforcing the urgent need for shoulder pain prevention strategies in this population. Despite the high prevalence of shoulder pain, a previous history did not influence the development of shoulder pain in this population, in contrast to previous studies, which have shown a history of shoulder pain as a risk factor for shoulder pain.[51]

Conclusions to be drawn from this study need to be tempered in light of some limitations. The questionnaire, although previously trialled, was not tested for reliability and was reliant on the reporting accuracy of swimmers. Although shoulder pain was defined in the questionnaire, pain was self-reported, which may have influenced results. It is possible that both a history of pain and subsequent shoulder pain were under-reported as the majority of swimmers believe mild to moderate pain is normal and should be tolerated.[70] Although groups had a similar mean age, shoulder pain history and training time, other variables may have influenced the development of shoulder pain in these swimmers such as range of shoulder rotation, frequency of dryland sessions, training intensity, competition, core stability and growth.[5] However, to date, not one of these variables have been shown to have a high level of certainty in predisposing a swimmer to shoulder pain[4] and to our knowledge there are no other prospective studies that have investigated shoulder strength and the development of shoulder pain in swimmers.

Our findings suggest that further investigation of shoulder EX strength as a risk factor for the development of shoulder pain in swimmers is worthwhile. We propose that the investigation of shoulder EX strength in combination with other factors, both modifiable and non-modifiable, may enhance our understanding of risk factors for shoulder pain in swimmers and provide direction for injury prevention programs.

6.6 Conclusion

Preliminary evidence supports an association between low shoulder EX strength and the development of shoulder pain in young male swimmers. Furthermore, predictive outcomes suggest that low shoulder EX strength may be a risk factor for the development of shoulder pain. Shoulder EX strength tests are a functional measure of the ability to produce force and stabilise around the shoulder and may prove to be a useful clinical indicator for young swimmers at risk of developing shoulder pain.

6.7 Practical Implications

- Shoulder EX strength is a potentially useful measurement in young swimmers and may be associated with the development of shoulder pain.
- Identification of male swimmers with shoulder EX strength less than 13.5% of BW may be helpful in the prevention of shoulder pain.
- Shoulder EX strength testing is functional for swimmers, as in addition to testing the capacity of the axioscapular and torque producing muscles, the rotator cuff muscles are tested in their role as shoulder stabilisers.

Chapter 7. Discussion

7.1 Major Outcomes

This thesis presents the major outcomes of reliability, descriptive and longitudinal investigations of shoulder strength and scapular UR in a young pain-free swimming population. The overall aim of this series of investigations was to determine any relationship between two commonly assessed and modifiable physical factors; shoulder strength and scapular UR, and the development of shoulder pain in young swimmers. To achieve this aim, reliable testing protocols specific to swimmers were established and employed to measure shoulder strength and scapular UR in 85 young swimmers. As previous research has suggested that shoulder pain can inhibit the generation of force in a strength assessment and may change scapular UR position, it was imperative to initially establish values for these factors in a pain-free swimming population.[46, 52, 85] Our prospective investigation based on the established data set for the pain-free swimmers investigated any relationship (associative or predictive) for shoulder strength and scapular UR and the development of shoulder pain.

7.1.1 Reliability

The results from reliability investigations demonstrated that the clinically useful testing protocols employed in this thesis are reliable. (Study 1 and Study 3) The positions chosen for measuring scapular UR, shoulder IR and ER (performed in 90° shoulder abduction); and EX and FL (in 140° shoulder abduction) are replicant of the elevated shoulder positions repeated in swimming, thus, provide a more functional profile for the swimmer compared to tests performed in a neutral shoulder position. Using a HHD and an inclinometer, the testing protocols can be easily replicated using portable tools, without additional assistance or equipment, deeming it convenient for a sole clinician testing in the clinic or poolside. Previous investigations have also reported high reliability for shoulder strength tests; however, manual stabilisation of the upper limb, scapula or trunk was provided.[17] Whilst good to excellent reliability (ICC 0.87-0.99) was confirmed for the current strength tests without manual support when performed in sitting, prone and supine positions, MDC values were lowest (≤11% BW) for all tests as a group when tested in the supine position. Few studies have reported MDC values for shoulder strength tested with a HHD;

however, one other study reported intra-rater reliability, with MDC ranges from 7.9-22.1% BW for shoulder ER and IR.[17] Typically, literature in this area describes reliability retesting within a few days.[14, 17] Retesting the reliability days apart simulates a clinical situation, and the excellent results (ICC 0.81-0.96, except at 140° shoulder abduction on the non-dominant arm; ICC 0.62) provided in this thesis should give clinicians confidence in using these measures in clinical practice in a way that is useful to them.

7.1.2 Shoulder strength

The second study in this research series established isometric shoulder strength values that are functional and specific to young swimmers, using the strength test protocol described (Study 1) in the supine position. For clinical utility, strength data for shoulder EX, FL, ER and IR have been normalised to BW for the dominant and non-dominant shoulders of males and females, allowing comparison of individuals of different sizes. Shoulder strength ratios, IR:ER and FL:EX were the same for males and females; however, as differences in relative shoulder strength were confirmed between sexes, shoulder strength rather than strength ratios are recommended as a more sensitive and informative measure. Similar side-to-side shoulder strength values were reported for this cohort of swimmers (Study 2), which is not surprising, given the bilateral nature of swimming.

7.1.3 Scapular UR

The large variability in scapular UR ranges found in the third study confirms previous research results[14, 15] and has demonstrated that normative values for this factor are of little value. We have added to the literature by providing original data suggesting that side to side symmetry for scapular UR is a reasonable expectation for the swimmer in the elevated shoulder positions described. Consequently, when treating unilateral shoulder pain, the clinician may use the non-painful shoulder as a valid reference point for shoulder strength and scapular UR position.

7.1.4 Predictive value

Based on the dataset of values for shoulder EX, FL, IR and ER strength, and scapular UR established in this thesis, a longitudinal investigation was conducted, formulating the fourth and final study. The data supporting the relationship between low shoulder EX strength and subsequent shoulder pain were collected over a two-year period. This gives strength to the findings, as swim studies of this duration do not appear in the literature. Shoulder EX strength tested in elevation may be useful in predicting shoulder pain. Strength values should account for BW, and the value of <13.5% appears to be a meaningful cut off value, giving clinicians direction for strength programs. In contrast, shoulder FL, IR, ER strength and scapular UR (**Appendix J**) did not have a statistically significant relationship to the development of shoulder pain in male or female swimmers. These results have implications for potential screening, intervention and prevention programs and are of interest to clinicians and coaches working with swimmers.

The work from this thesis has made a significant contribution to a swimming assessment through the provision of relative shoulder EX, FL, IR and ER strength values and parameters for scapular UR for young swimmers. The data set, collected from pain-free swimmers, informs the clinical assessment of these modifiable physical factors and provides a useful reference for clinicians. Furthermore, this work has highlighted the importance of assessing swimmers' shoulder EX strength in elevation. This clinical test which is easy to perform, may be important in identifying swimmers at risk of developing shoulder pain (particularly young males). In contrast to shoulder IR and ER strength, the significance of shoulder EX strength, tested in elevation, has not previously been described in the swimming literature.

7.2 Clinical Implications

7.2.1 Methodology

The strength testing protocol employed in this project demonstrated high reliability for a clinician of smaller size (56kg) ensuring that it can be replicated by most clinicians. As tester strength and size has been identified as influencing HHD test reliability, aspects of the test protocol were included to aid reliability of testing in the clinic, increasing utility for all clinicians.[98, 101] Normative values were generated in supine, which provided a stable base for the swimmer and was also conducive for an optimal and ergonomic tester position. Furthermore, reliability testing demonstrated MDC values less than or equal to 11% BW for the whole group of strength tests performed in supine compared to MDC values up to 15% BW for FL in prone and 14% BW for IR in sitting (Study 1). A *make* test was chosen over a *break* test to further improve the reliability[99, 100], ease of testing and comfort for the swimmer. Without the eccentric phase and higher forces of a *break* test, it was postulated that the risk of shoulder pain for the swimmers during or after testing was reduced, providing a comfortable, safe and clinically useful test protocol.

7.2.2 Baseline measures and monitoring

In the presence of pain, a deficit in any shoulder strength test may indicate either inhibition of force in the direction tested or true weakness. Previous investigations of swimmers' shoulder strength and scapular UR may be limited by testing performed in the presence of shoulder pain.[36, 37] Strength tests will be more informative if baseline measures are recorded in the pain-free state, minimising muscle inhibition due to pain. Following a baseline assessment, regular monitoring of shoulder strength throughout a swim season may provide an early indication of strength reduction or inhibition before ongoing pain becomes a problem. There may be potential to use the strength tests described in this thesis to monitor training loads as the tests are simple and easy to administer. A reduction in the ability to produce previous force levels could be an early indicator of a pending shoulder problem suggesting the need for increased monitoring or reduced loading of the shoulder.[138]

7.2.3 Normative strength data

Prior to this research, shoulder strength data normalised to BW have not been available for clinicians to use as a reference point for assessment when using a HHD. Swimmers with shoulder pain commonly undergo a clinical assessment of shoulder strength and scapular UR in order to identify physical deficits. A deficit may be determined via two ways: either by comparison with the non-painful or uninjured opposite side or by using a reference value defined as normal for the relevant population and age. However, there is a paucity of shoulder strength data available for swimmers and it is difficult for clinicians to utilise the information due to limitations which include; absolute data, which is not useful for comparison, isokinetic data, which is difficult to replicate clinically, small sample sizes, the presence of pain during tests, confounding results and varied protocols that are difficult to replicate.[18, 36, 87]

Furthermore, shoulder rotation strength has been the focus of most studies exploring swimmers' shoulder strength, providing a limited shoulder strength profile for swimmers. Clinicians can use the research presented here to compare strength test outcomes with swimming specific shoulder strength values normalised to BW in addition to shoulder strength ratios when assessing a swimmer with shoulder pain or screening a pain-free swimmer. This capacity for valid side-to-side comparison is unique to swimming, a bilateral sport. Athletes involved in unilateral sports such as tennis or throwing have demonstrated differences in shoulder strength and scapular UR values for the dominant and non-dominant shoulders so side-to-side comparisons are not useful.[122, 127]

7.2.4 Shoulder EX and FL strength

Shoulder EX and FL strength tests, performed in shoulder elevation, have not previously been reported in the swimming literature but are highly relevant to further our understanding of overall shoulder strength in swimmers. In the assessment of swimmers' shoulder strength, low strength will provide information regarding the ability to produce force in a direction rather than deficits for a specific muscle. As the rotator cuff muscles have more of a stabilising role in EX and FL and a direction specific torque-producing role in shoulder IR and ER strength tests, these strength tests all provide information regarding rotator cuff muscle function.[77] Investigations have previously reported IR and ER strength values and recommended rotator cuff strengthening exercises.[21, 29] However, shoulder EX and FL are also important directions in which to test shoulder strength and challenge rotator cuff function, informing interventions. The novel shoulder EX and FL strength data add value to the clinical assessment of a shoulder, aid clinical decision making and may offer some direction for rehabilitation.

7.2.5 Potential risk factor

Low shoulder EX strength in male swimmers is potentially a modifiable risk factor for the development of shoulder pain. This preliminary evidence might be extremely important for the clinician and coach working with young swimmers and justifies including shoulder EX strength tests in a swimmer's assessment. A young male swimmer who trains six or more hours a week with pain-free shoulder EX strength below 13.5% BW, may be at risk of developing shoulder pain. Although further confirmation is required with larger swimming populations, this evidence provides some indication that low shoulder EX strength in swimmers is worth monitoring. As the time and cost benefit of providing a strength intervention monitoring this swimmer is small, an opportunity is provided to potentially reduce the risk of shoulder pain developing in a young male swimmer.

7.3 Limitations

7.3.1 Sample size

Eighty-five swimmers were tested for shoulder strength and scapular UR and 47% returned questionnaires, providing data for 74 shoulders. Although this number met the requirements for sample size for the roc analysis, a larger sample size would further increase the power of the prospective investigation (Study 4). However, there were a limited number of swimmers available for testing who trained at least six hours a week and met the pain-free criteria described (free of shoulder pain that caused training to stop or change on two occasions in the two months prior to testing). It is well documented that a high number of swimmers report shoulder pain, with up to 91% of swimmers younger than 25 years reporting shoulder pain[1, 5, 28] Furthermore, even though sourcing pain-free swimming participants was challenging, it is possible that pain and a history of pain were underreported within this sample, given that many swimmers believe that shoulder pain is normal and most swimmers continue to train with pain.[70]

7.3.2 Questionnaire

The questionnaire used in study four provided some limitations to this prospective investigation. Although tested on a swimmer and physiotherapist for clarity, the validity and reliability of our questionnaire was not investigated. Weekly reports of pain using a questionnaire such as the Oslo Sports Trauma Research Center (OSTRC) Overuse Injury Questionnaire[42] could be employed in future studies. A high response rate, up to 81% has been reported for this reliable and valid questionnaire; however, this was for an elite sporting group monitored over a shorter time frame of 13 weeks.[42] With a satisfactory response rate (47%), our questionnaire was short, relevant to the swimmers and included a university logo and follow up; all factors demonstrated to enhance response rate.[139] The definition of shoulder pain, used for the questionnaire and in testing, was based on time loss and may have failed to identify the true magnitude of the problem.[42] Although the definition of shoulder pain as "any physical complaint of the shoulder" may quantify the problem more realistically, it is highly subjective, with a risk of overreporting episodes compared to the time loss definition.

7.4 Future Directions

7.4.1 Confirm relationship of shoulder EX strength to shoulder pain

This investigation has provided preliminary evidence of a relationship between shoulder EX strength and the development of shoulder pain in young male swimmers. Although there was a significant difference in shoulder EX strength between shoulders with and without reported pain for males (12% and 17% BW respectively; p=0.04), the MDC for shoulder EX strength in the reliability study (Study 1) ranged between 6-11.0% BW (dominant and non-dominant shoulder respectively). This means that measurement error may have exceeded the strength difference (5% BW) calculated for male shoulder EX strength in supine. We acknowledge that the strength difference demonstrated may be partly attributable to measurement error, although the prospective study did not involve a test-retest situation. Interestingly, the MDC for the shoulder EX strength tests when performed in prone, ranged from 2-4% BW. However, supine was chosen as the test position as the lowest MDC for the entire group of strength tests was demonstrated in supine, making it efficient for the solo clinician to administer all tests. To further investigate shoulder EX strength specifically, the prone position is recommended, due to the smaller MDC in this position.

Further prospective investigation with more rigorous monitoring of variables and subsequent shoulder pain onset for both sexes is warranted. A continuous monitoring questionnaire (OSTRC)[140] or reporting system using a software application or Short Message Service (SMS) might improve reporting accuracy[141] and provide more scope for inclusion of detail related to training load, pain and time off due to injury. Swimmers could enter training data and pain status on a weekly basis over a two-year period; however, with such approaches, compliance may be comprised by this large commitment. Training data could be confirmed by coaches for accuracy and a clinician could assess the swimmer if shoulder pain was reported, providing injury detail. To monitor growth, additional height and arm span measurements could be taken at four-month intervals over the two-year period for this developing cohort. An increased injury rate has been reported during times of rapid growth, monitored via peak height velocity calculations.[142] Arm span relative to height could be calculated and matched with strength measures staged over the time monitored. This could be particularly important for EX strength, given the significant results for young males as reported in this thesis.

7.4.2 Other modifiable factors

In addition to shoulder strengthening, core endurance training and reduced swimming exposure have been recommended as interventions that may help prevent shoulder pain in swimmers.[5] A swimmer with reduced core strength may be more reliant on the shoulder for force production and subject the shoulder to increased stress. One could hypothesise that a swimmer with reduced core strength or indeed, lower limb strength is more at risk of developing shoulder pain when exposed to increased training loads compared to a swimmer with optimal strength in these regions. A baseline assessment combining outcomes for core, lower limb and upper limb strength could describe the overall strength of a swimmer and generate a normal reference range. Following the establishment of these strength measures (core, lower limb and upper limb), a longitudinal investigation monitoring training load and any onset of shoulder pain for swimmers may help to determine any relationship of these strength measures (individually or combined) with the development of shoulder pain.

7.4.3 Scapular UR

In the presence of pain, changes to scapular UR position are inconsistent and have been described as increased,[52] decreased[107] and unchanged.[105] Very few studies have explored scapular UR position in swimmers. One study with a small sample size of 20, reported increased scapular UR in swimmers after shoulder pain was experienced during a swim training session.[13] In the study by Su et al.,[13] changes to scapular UR were clinically small (2.5-4.0°); however, the results suggest further investigation of scapular UR is warranted in swimmers. There is little information describing scapular UR in the swimmer with resolved shoulder pain in comparison to the position recorded in the presence of pain. Future studies should confirm this with larger sample sizes, monitoring scapular UR pre and post training and recording the presence of pain. It would be interesting to explore if scapular UR changes are a precursor to pain, the result of pain, or if the position is unaffected.

7.4.4 Shoulder EX strength exercise intervention.

Dry-land exercise programs have been recommended for swimmers with the aim of injury prevention.[29, 61] However, programs may lack direction as clarity around risk factors has been lacking. The findings in this thesis suggest that young male swimmers with low shoulder EX strength (<13.5% BW) may be at risk of developing shoulder pain. Confirmation of the significance of this finding and its application to injury prevention could be investigated further. A dry land shoulder EX strength intervention program could be provided to swimmers over a 12-week period. Shoulder EX strength measurements could be compared between this group and a control group before and after an intervention program and any onset of shoulder pain could be monitored during and after the program.

7.5 Conclusions

The findings from this thesis inform sports clinicians and coaches working with young swimmers and provide an early indicator which may help identify young males at risk of developing shoulder pain. Clinical reasoning and treatment programs can now be founded on normative shoulder EX, FL, IR and ER strength and scapular UR data that are specific to the sport and not affected by pain. Shoulder EX strength measured in 140° shoulder abduction has not previously been evaluated but has high functional relevance to swimming. Using a clinically applicable protocol, this novel strength test was found to be reliable and informative. Although the research conducted in this thesis did not support that scapular UR position, shoulder FL, IR and ER strength were associated with the development of shoulder pain in young swimmers, low shoulder EX strength in young male swimmers was an indicator that this group may be at increased risk of developing shoulder pain. With a scarcity of clear evidence for modifiable risk factors for this widespread problem in swimmers, shoulder EX strength is worthy of further investigation and should be included in a swimmer’s shoulder assessment to help identify and monitor young male swimmers who may be at risk of developing shoulder pain.

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Appendices

Appendix A *Information sheet for reliability study (study 1)*

Shoulder Position and Strength Testing

Information Sheet

You are invited to take part in a research study investigating the reliability of measuring shoulder position and strength.

Ms Marie-Louise Bird and Dr James Fell from the School of Human Life Sciences, University of Tasmania, Launceston and Ms Sally McLaine from Active Physiotherapy, Launceston, are conducting the study.

Before you decide whether or not you wish to participate in this study, it is important for you to understand why the research is being done and what it will involve. Please take your time to read this information carefully and discuss it or ask any questions if you wish.

Introduction and Purpose

Shoulder pain is a common injury complaint for people of many ages and can result in time away from work and sport. Various factors may contribute to shoulder pain such as repetitive movements, shoulder muscle weakness, poor core control, poor flexibility, postural habits and previous injury. Studies have demonstrated different findings with respect to strength and shoulder blade position in people with and without shoulder pain. The deep muscles around the shoulder and shoulder blade help control shoulder movement and correct positioning during overhead movements. If these muscles are weak then pain and injury to the shoulder tendons may result.

The aim of this research study is to measure the strength of the shoulder in various positions and to measure the position of the shoulder blade at rest and in an elevated position in people without shoulder pain using two small hand-held devices. These results may be used for future studies, to help determine optimal positions for testing using these tools

Participants

People aged between 18-30 years who do not have shoulder pain.

Procedure

If you choose to participate in this study you are required to:

1. Complete a questionnaire about any previous shoulder pain and your general activity levels (sport).
2. Have your height and weight recorded.
3. Participate in a testing session on two separate occasions.
4. Have your shoulder strength tested in 6 different positions. This will be done using a simple hand held pressure measurement device. You will be asked to push against it as hard as you can 2 times for each test on each side (for a total therefore of 12 times for each shoulder)
5. Have your shoulder blade position measured in standing with your arm resting by your side, arm elevated to shoulder height and above the shoulder. This will be performed by placing a simple angle measuring device on the shoulder blade.
6. Return for the same testing procedure to be repeated after 48 hours.

It is anticipated that this will take no longer than 20-30 minutes for each session. There will be two sessions 48 hours apart. A physiotherapist will be performing the strength tests. Please inform the physiotherapist if you experience any pain during the testing.

Possible Risks

This is a low risk testing activity but participants are advised to inform the investigator if they experience any shoulder pain during or after the testing. As this testing involves uninjured shoulders it is extremely unlikely for people to experience pain when performing a strength test. If pain is experienced, it is likely to be minor and will respond well to ice treatment.

Benefits

We hope that research such as this will provide more information about the reliability of testing strength and shoulder blade position in people without shoulder pain. This will establish reliability of the testing protocol and determine which position is more reliable for these tests. We hope that it will help in the future to reliably test people with shoulder problems or weakness and assist with assessing and managing people with shoulder pain. However, there will be no direct benefit to you as a result of the research performed.

Cost

Participation in this trial will not result in any costs for you and there is no payment for participation in this study.

Confidentiality

All data will be treated in the strictest of confidence and will be securely stored in locked files in the university. The information that will be collected will only be used for the purposes of this research. Records showing your identity will not be made publicly available. Your identity will remain confidential if the results of the testing are published. If reference to you is made, this will only be done using code numbers.

Participation and Withdrawal

Your participation is voluntary and you may withdraw at any time without giving a reason. All of your data can be destroyed if requested.

Inclusion and Exclusion

To undergo testing in this study you must not have experienced shoulder pain or injury in the last 2 months. You must not have a history of shoulder or neck surgery, shoulder dislocation or neurological disturbances. You need to be between the ages of 18-30 years.

Withdrawal

If you choose to withdraw at any stage, you may request that any of your data collected for the study be destroyed. The researches will act in accordance with your wishes.

Results

The results of this study will be analysed and presented as group data only. A summary of results will be available at the end of the study and these results will be provided to you if you wish.

Questions and Contacts

When you have read this information if you have a question about the study, you may call: Sally McLaine 04........ or email smclaine@utas.edu.au

This study has been approved by the Human Research Ethics Committee (Tasmania) Network in accordance with the National Health and Medical Research Council's guidelines.

If you have any concerns of an ethical nature or complaints about the manner in which the project is conducted, you may contact the Executive Officer of the Tasmanian Human Research Ethics Committee (Tasmania) Network on 62267479 or human.ethics@utas.edu.au. The ethics reference number for this study is H0013807.

Thank you for taking the time to consider taking part in this research. If you wish to volunteer, please sign the attached consent form.

Kind Regards

Sally McLaine

Appendix B *Consent form for reliability study*

Shoulder Position Measurement and Strength Testing

1. I, ____________________________ have read the information sheet and I agree to take part in the study investigating the reliability of shoulder position and strength measures.

2. I have received an explanation of the nature, purpose and foreseeable effects of the research. I understand what I am expected to do, and the estimated time required for the testing. The possible risks and benefits have been explained to me. I am to inform the investigator if I have a history of shoulder pain. I was given opportunity to read an information sheet and ask questions that were answered to my satisfaction.

3. I am aware that a Human Research Ethics Committee (Tasmania) has subjected this study for review and approval.

4. I understand that I am free to withdraw from the study at any time, without any effect.

5. I understand that if the results of the study are published or presented that my name and details will be kept confidential.

6. I understand that participation involves no foreseeable risks.

7. I understand that all research data will be kept confidential and will be securely stored on site at the University of Tasmania.. I voluntarily consent to participate in this study.

Subject's Signature____ Date ______

Investigator Statement

I, ____have explained this study and the implications of participating in it to the volunteer and I believe that the consent is informed and that he/she understands the implications of participating in this study. The participant consented to participate by his/her personally dated signature.

Investigator's Signature____ Date________

Witness' Signature ____Date _

Appendix C *Poster presentation for reliability of shoulder strength tests (study 1)*

The reliability of shoulder strength tests for the overhead athlete using a hand-held dynamometer

Sally J. McLaine [a], Karen A. Ginn [b], Cecilia M. Kitic [a], James W. Fell [a] and Marie-Louise Bird [a]
[a] Sport Performance Optimisation Research Team, School of Health Sciences, University of Tasmania, Australia
[b] Discipline of Biomedical Science, Sydney Medical School, University of Sydney, Australia

Introduction

The reliable measurement of shoulder strength is important when assessing the athlete involved in overhead activities. Swimmers' shoulders are subject to repetitive humeral elevation and consequently have a high risk of developing movement control issues and pain[1]. Shoulder strength tests performed in positions of elevation assist with the detection of strength deficits that may impact on performance and injury in overhead sports like swimming. Clinicians use hand-held dynamometers to objectively measure strength as these portable tools are affordable and have previously demonstrated good reliability for tests below shoulder height[2]. The reliability of isometric shoulder strength tests performed in positions of humeral elevation without manual stabilisation has not been established.

Objective

To establish the relative and absolute intra-rater reliability of shoulder strength tests functional to swimming in three body positions commonly used in the clinical setting.

Materials and Methods

Design: Repeated measures, reliability study.

Subjects: Fifteen university students and staff (mean age 24 years ± 8.2) without shoulder pain

Intervention: Isometric shoulder strength tests were performed in positions of humeral elevation (flexion and extension in 140° abduction in the scapular plane; internal and external rotation in 90° abduction) in a randomised order. Subjects were tested in supine, prone and sitting by one examiner with a hand-held dynamometer and retested, replicating test order, after 48 hours.

Main Outcome Measures: Relative reliability ($ICC_{3,1}$) values with 95% confidence interval. Absolute reliability was reported by minimal detectable change (MDC).

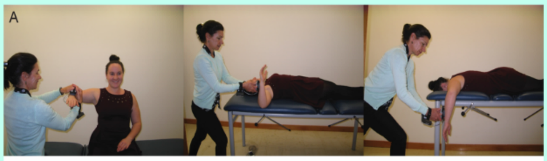

Figure A. Shoulder rotation strength tests in sitting, supine and prone positions.

Figure B. Flexion and extension strength tests in sitting, supine and prone positions.

Figure C. Hand entry position for butterfly.

Figure D. Overhead arm position in tennis.

Results

Table 1. Intra-rater reliability of flexion and extension shoulder strength tests for sitting, supine and prone positions.

Test	Position	Test1 (N)	Test2 (N)	ICC (95% CI)	SEM (N)	MDC_{90}(N)	%MDC
FL DOM	Sitting	46.6 (18.6)	48.4 (16.9)	0.94 (0.82-0.98)	2.15	5.02	10.57
	Supine	64.4 (24.6)	60.5 (22.3)	0.94 (0.82-0.98)	2.76	6.43	10.30
	Prone	36.7 (8.6)	35.8 (10.6)	0.87 (0.62-0.96)	2.38	5.54	15.3
FL NON	Sitting	45.3 (15.1)	45.3 (18.7)	0.93 (0.78-0.98)	2.70	6.30	13.90
	Supine	61.3 (21.8)	60.7 (21.0)	0.94 (0.81-0.98)	2.67	6.21	10.19
	Prone	35.5 (10.7)	35.9 (11.1)	0.93 (0.79-0.98)	1.51	3.53	9.87
EXDOM	Sitting	59.2 (25.4)	62.0 (22.5)	0.96 (0.88-0.99)	1.86	4.34	7.15
	Supine	73.2 (42.5)	71.7 (41.3)	0.98 (0.94-0.99)	1.74	4.05	5.59
	Prone	79.1 (41.1)	79.7 (36.9)	0.98 (0.95-0.99)	1.51	3.52	4.43
EX NON	Sitting	60.8 (32.2)	60.6 (28.6)	0.97 (0.90-0.99)	1.91	4.45	7.34
	Supine	74.9 (40.7)	74.7 (39.8)	0.96 (0.87-0.99)	3.53	8.25	11.02
	Prone	77.0 (35.1)	78.1 (37.5)	0.99 (0.97-0.99)	0.78	1.82	2.34

Abbreviations: CI, confidence interval; DOM, dominant arm; EX, extension; FL, flexion; ICC, intraclass correlation coefficient; MDC, minimal detectable change; N, newtons; NON, nondominant arm; SEM, standard error of measurement.

- ❑ Good to excellent intra-rater reliability was found for all shoulder strength tests (ICC 0.87-0.99).
- ❑ Intra-rater reliability was not affected by body position.
- ❑ MDC% was 15% or less for every strength test and below 11% for tests performed in supine.
- ❑ Intra-rater reliability was not affected by arm dominance.

Conclusion

- ❑ Shoulder flexion, extension, internal and external rotation strength tests performed in humeral elevation demonstrated excellent to good intra-rater reliability regardless of body position.
- ❑ A strength change of more than 15% in any position can be considered meaningful.
- ❑ If clinicians perform all tests then supine is recommended as MDC values remained below 11% and this is an ergonomic position for the tester.

Acknowledgements

- ❑ Justin Ockerby for assistance with testing and photographs.
- ❑ SARRAH for scholarship support.

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Appendix D *Table for Intra-rater reliability for degrees of scapular upward rotation in 90° and 140° shoulder abduction*

Shoulder position	Side	Test 1	Test 2	ICC (95%CI)	SEM	MDC95
90° abduction	**D**	25.9 (9.0)	31.1 (6.1)	0.76 (0.50-0.90)	2.4	6.5
	ND	25.0 (5.4)	30.1 (5.6)	0.86 (0.69-0.94)	1.2	3.2
140° abduction	**D**	52.5 (5.2)	50.7 (7.3)	0.83 (0.62-0.93)	1.3	3.5
	ND	49.7 (6.4)	50.1 (5.2)	0.62 (0.27-0.83)	2.7	7.5

Abbreviations: CI, confidence interval; D, dominant; ICC, Intraclass Correlation Coefficient; MDC, minimal detectable change; ND, non-dominant; SEM, standard error of measurement.

Appendix E *Recruitment letter to coaches*

Dear Swim Coach,

I am conducting research as a physiotherapist investigating shoulder position and strength in young swimmers and would like to invite your swim squad to take part with your permission.

There may be long-term benefits for your swimmers in knowing if they have a significant weakness of the shoulder.

If you agree for your squad to take part each swimmer (aged between 14-20 years) can receive a detailed information form about the research, which is attached to this letter for your information.

After reading the information form, if the individual swimmer (and their parent if they are under 18 years old) consents to volunteer they will be asked to:

1. Fill out a questionnaire and consent form.

2. Undergo a shoulder strength test using a simple hand held device.

3. Undergo measurement of their shoulder blade position at rest and in arm elevation, using a simple angle measurement tool.

4. Have their height and weight measured.

The study will exclude swimmers who have had shoulder surgery or currently have shoulder pain. The testing will take place at the pool or another preferred venue at a time that is mutually agreeable.

If, after reading the information sheet you would like your squad to take part please sign the form attached. If you would like to discuss this or have any questions at all please do not hesitate to contact me via email: smclaine@utas.edu.au or phone: 04.........

Kind Regards

Sally McLaine

APA Sports Physiotherapist

Appendix F *Swimmers' Information Sheet*

Shoulder Position and Strength Testing in Swimmers

Information Sheet

You are invited to take part in a research study investigating shoulder position and strength in swimmers.

Ms Marie-Louise Bird and Dr James Fell from the School of Human Life Sciences, University of Tasmania, Launceston, Associate Professor Karen Ginn from The University of Sydney and Ms Sally McLaine from Active Physiotherapy, Launceston, are conducting the study.

Before you decide whether or not you wish to participate in this study, it is important for you to understand why the research is being done and what it will involve. Please take your time to read this information carefully and discuss it or ask any questions if you wish.

Introduction and Purpose

Shoulder pain is the most common injury complaint in swimmers of all ages and can result in time away from training and competition, possibly even terminating participation. Various factors may contribute to swimmers' shoulder pain such as the repetitive nature of training, shoulder muscle weakness, poor core control, poor flexibility, training errors, postural habits and previous injury. Recently, a study reported that high school age swimmers were the most symptomatic and had the highest load of training hours. Other studies have demonstrated different findings with respect to strength and shoulder blade position in swimmers with and without shoulder pain. The deep muscles around the shoulder and shoulder blade help control shoulder movement and correct positioning during overhead movements. If these muscles are weak then pain and injury to the shoulder tendons may result.

The aim of this research study is to measure the strength of the shoulder in various positions and to measure the position of the shoulder blade at rest and in an elevated position in swimmers without shoulder pain. These results may be used as a comparison in a future study, with results taken from swimmers who have recently had shoulder pain.

Participants

Swimmers aged 14-20 who swim train at least 4 times a week (minimum of 6 hours) and have not recently (in the last 2 months causing the swimmer to miss 2 or more sessions) had shoulder pain.

Procedure

If you choose to participate in this study you are required to:

7. Complete a questionnaire about any previous shoulder pain and your training volume in the water and on land.
8. Have your height and weight recorded.
9. Participate in a testing session on one occasion before your swimming training.
10. Have your shoulder strength tested in 4 different positions. This will be done using a simple hand held pressure measurement device. You will be asked to push against it as hard as you can 2 times for each test on each side (for a total therefore of 8 times for each shoulder)
11. Have your shoulder blade position measured in standing with your arm resting by your side, arm elevated to shoulder height and above the shoulder. This will be done by placing a simple angle measuring device on the shoulder blade.

It is anticipated that this will take no longer than 20-30 minutes. A physiotherapist will be performing the strength tests. Please inform the physiotherapist if you experience any pain during the testing.

Possible Risks

This is a low risk testing activity but participants are advised to inform the investigator if they experience any shoulder pain during or after the testing. As this testing involves uninjured shoulders it is extremely unlikely for people to experience pain when performing a strength test. If pain is experienced, it is likely to be minor and will respond well to ice treatment.

Benefits

We hope that research such as this will provide more information about strength and shoulder blade position in young swimmers without shoulder pain. This will provide a baseline measurement for comparison when studying young swimmers who have shoulder pain. We hope that it will help in the future to provide recommendations on the prevention of and best treatment for managing shoulder pain in swimmers. However, there will be no direct benefit to you as a result of the research performed.

Cost

Participation in this trial will not result in any costs for you and there is no payment for participation in this study.

Confidentiality

All data will be treated in the strictest of confidence and will be securely stored in locked files in the university. The information that will be collected will only be used for the purposes of this research. Records showing your identity will not be made publicly available. Your identity will remain confidential if the results of the testing are published. If reference to you is made, this will only be done using code numbers.

Participation and Withdrawal

Your participation is voluntary and you may withdraw at any time without giving a reason. All of your data can be destroyed if requested.

Inclusion and Exclusion

To undergo testing in this study you must not have experienced shoulder pain in the last 2 months, which has resulted in you not swim training for 2 or more sessions. You must not have a history of shoulder surgery. You need to be between the ages of 14-20 years and participate in swim training sessions 4 or more times a week.

Withdrawal

If you choose to withdraw at any stage, you may request that any of your data collected for the study be destroyed. The researches will act in accordance with your wishes.

Results

The results of this study will be analysed and presented as group data only. A summary of results will be available at the end of the study and these results will be provided to you if you wish.

Questions and Contacts

When you have read this information if you have a question about the study, you may call:

Sally McLaine on 04........ or email smclaine@utas.edu.au

This study has been approved by the Human Research Ethics Committee (Tasmania) Network in accordance with the National Health and Medical Research Council's guidelines.

If you have any concerns of an ethical nature or complaints about the manner in which the project is conducted, you may contact the Executive Officer of the Tasmanian Human Research Ethics Committee (Tasmania) Network on 62267479 or human.ethics@utas.edu.au. The ethics reference number for this study is H0012936.

Thank you for taking the time to consider taking part in this research. If you wish to volunteer, please sign the attached consent form.

Kind Regards

Sally McLaine

APA Sports Physiotherapist

Appendix G *Consent form for Swimmers*

Shoulder Position Measurement and Strength Testing In Swimmers

1. I, ___________ have read the information sheet and I agree to take part in the study investigating shoulder position and strength in swimmers.

2. I have received an explanation of the nature, purpose and foreseeable effects of the research. I understand what I am expected to do and the estimated time required for the testing. The possible risks and benefits have been explained to me. I am to inform the investigator if I have a history of shoulder pain. I was given opportunity to read an information sheet and ask questions that were answered to my satisfaction.

3. I am aware that a Human Research Ethics Committee (Tasmania) has subjected this study for review and approval.

4. I understand that I am free to withdraw from the study at any time, with out any effect.

5. I understand that if the results of the study are published or presented that my name and details will be kept confidential.

6. I understand that participation involves no foreseeable risks.

7. I understand that all research data will be kept confidential and will be securely stored on site at the University of Tasmania.

I voluntarily consent to participate in this study.

____

Subject's Signature

____

Parental Consent (if subject is under 18)

Date ______________

Investigator Statement

I, ____ have explained this study and the implications of participating in it to the volunteer and I believe that the consent is informed and that he/she understands the implications of participating in this study. The participant (and the parent if required) consented to participate (or for their child to participate) by his/her personally dated signature.

Investigator's Signature ____________________________________Date _______________

Witness' Signature ____Date _______________

Appendix H *Testing Questionnaire*

Shoulder Testing in Swimmers

Swimmers' Questionnaire

ID:

1. Name: ______________

2. Age: _______ Gender: M / F

3. Phone:_______________

4. Email:_____________________________

   Preferred option for contact: phone/email

5. Do you have a history of any of the following?
   a. Shoulder surgery □ yes □ no
   b. Neck surgery □ yes □ no
   c. Shoulder injury □ yes □ no
   d. Neurological condition □ yes □ no

   Details:____

   Any other condition(s) that may affect shoulder strength? ____________________

Swim History:

1. Number of pool sessions/week :_
2. Hours of swimming per week:_________
3. Number of dry land sessions/week:

   Gym:___ Run:___ Pilates:____ Other:________

4. Time in competitive swimming: __________Level: Club/ State/ National (circle)
5. Preferred stroke:_ ____________________
6. Best 100m freestyle time:_____________ Approximately when?_________
7. Do you participate in other sports?___________________

What sport?___________________________

Number of times per week?______________

Shoulder History:

1. Which hand do you: 1. Write with?___________2. Throw a ball with? _________
2. Have you ever had shoulder pain that has stopped you training? ________

   Which side?__________When? ___________________________

   How long were you off training? Tick one: □ <7 days; □ 7-21 days; □ >21 days

   Please give any more details:______________________________
3. Do you have shoulder pain now?_____________ In the past week?____________

Thank you for taking the time to complete this questionnaire, please return it to us in the prepaid envelope with the consent form.

If you have any questions, please contact Sally McLaine on 04........ or email smclaine@utas.edu.au

Thank you for your time and participation.

Appendix I *Follow-Up Questionnaire*

Shoulder position and strength testing

Follow-Up Questionnaire

You are invited to complete this survey as part of a follow up for the shoulder strength testing that you participated in [redacted]

We are keen to investigate the relationship between shoulder strength and pain, and would be grateful if you could take a few minutes to answer the following questions, even if you have no pain or are no longer training. By completing and returning this form you are consenting to the use of the information for the same investigation of swimmers' shoulder strength with the ethics reference number: [redacted].

The questions apply <u>only to the time period since</u> your shoulder strength and shoulder blade movement testing.

1. Name: _________________________________

2. Club: __________________________________

3. What is your best 100m freestyle time? ____________________

4. Do you currently (today) have any shoulder pain?

R________L________ BOTH________

5. Have you had shoulder pain since being tested for this research project?

R________L________ BOTH________

How long have you had pain for? ____________________

6. If you have had pain, has this resulted in you missing training or competition? Yes____ No____

Number of sessions missed: ________ (Best approximation)

Number of sessions modified: _______ (Best approximation)

7. Over the past 6 months please estimate averages as best as you can for the following:

a) Swim training hours/week ____________

b) Swim distance/ week _______________

c) Land sessions/week ________________

8. If you are no longer swim training or have had a break of longer than one month please state reason/s: ____

Any other comments? ____

Thank you for taking the time to complete this questionnaire.

If you have any questions, please contact [redacted]

Thank you for your participation.

Appendix J *Table of results for of scapular UR position comparison (study 4)*

Comparison of median (range) scapular UR position in degrees, between shoulders with and without reported pain (from questionnaire, study 4)

Shoulder abduction position	**Female shoulders**			**Male shoulders**		
	Pain reported n=15	**No pain reported** n=23	**p**	**Pain reported** n=12	**No pain reported** n=24	**p**
90°	30.0 (20-44)	29.0 (15-48)	0.86	34.5 (23-46)	32.5 (11-42)	0.22
140°	47.0 (35-60)	50.0 (39-69)	0.07	55.5 (35-70)	54 (39-63)	0.42

Appendix K *Poster presentation for preliminary results from follow up questionnaire (12 months)*

Awarded Best Clinical Poster at SMA Conference, 2017

IS SHOULDER STRENGTH RELATED TO THE DEVELOPMENT OF SHOULDER PAIN IN SWIMMERS?

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PURPOSE

Shoulder pain in swimmers is common.

Shoulder strength and strength ratios have been reported as potential modifiable risk factors associated with shoulder pain.

Different strength values and strength ratios for internal rotation (IR) and external rotation (ER) have been found in swimmers with shoulder pain compared to those without pain but the level of certainty that shoulder strength is a risk factor is low[1,2].

Shoulder flexion (FL) and extension (EX) strength, functionally relevant for swimmers when measured in elevation, may provide further insight in profiling the strength of a swimmer and in examining the relationship between shoulder strength and shoulder pain in swimmers.

The aim of this study was to determine if there is a relationship between relative shoulder strength or shoulder strength ratios and the development of shoulder pain in swimmers.

METHODS

PARTICIPANTS

Eighty-five swimmers (mean age 15.5; range 14-20 yrs) without shoulder pain were recruited by invitation from local swim clubs.

Minimum training six hrs/week.

PROCEDURE

One session of a shoulder strength assessment using a hand-held dynamometer was performed prior to training. Swimmers were followed up over a period of 6-9 months by email to determine the onset of any shoulder pain (defined as modified or missed training on two or more occasions) subsequent to testing.

ANALYSIS

Strength (as a % of body weight), ER:IR and FL:EX strength ratios were calculated.

Mann Whitney U tests investigated differences between swimmers who did and did not report shoulder pain.

FIGURE A. ER and IR in 90°abduction

FIGURE B. FL and EX in 140°abduction in the scapular plane

RESULTS

85 swimmers tested

42%

returned surveys from 76 emailed (32 people = 64 shoulders)

28 SHOULDERS PAIN		36 SHOULDERS NO PAIN	
17 ♀ SHOULDERS	11 ♂ SHOULDERS	17 ♀ SHOULDERS	19 ♂ SHOULDERS
^IR:ER 1.04 (0.60)	IR:ER 1.22 (0.50)	^IR:ER 1.17 (0.83)	IR:ER 1.22 (0.52)
FL:EX 0.97 (1.14)	*FL:EX 0.98 (0.65)	FL:EX 0.94 (0.53)	*FL:EX 0.84 (0.95)

Values show median (range)

**p=0.05*

^p=0.08

There were no significant differences in shoulder strength values between the shoulders that developed subsequent pain and the shoulders that did not (p>0.05)

CONCLUSIONS

There is no significant relationship between relative shoulder strength measures and the development of shoulder pain in young swimmers.

There may be a relationship between a higher FL:EX shoulder strength ratio and a lower IR:ER ratio and the development of shoulder pain in males and females respectively; further investigation is warranted.

REFERENCES

1. Tate, A et al. (2012) Risk factors associated with shoulder pain and disability across the lifespan of competitive swimmers. *Journal of Athletic Training: 47 (2) 149-158.*
2. Hill, L et al. (2015) Risk factors for shoulder pain and injury in swimmers: A critical systematic review. *The Physician and Sportsmedicine: 43 (4) 412-420.*

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S·A·R·R·A·H

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